University of Alberta

A Late Pleistocene and Holocene Phytolith Record, Lower Salmon River Canyon, Idaho.

by

Bradley F. Somer ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree Master of Arts

Department of Anthropology

Edmonton, Alberta

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Abstract

Phytolith analysis of two sediment exposures from the Lower Salmon River Canyon, Idaho, was carried out to provide a record of past vegetation. Six phytolith zones were defined, spanning full glacial time to the present.

The results are also compared to those of Davis (2001) in order to test the 'Oasis effect' hypothesis. This hypothesis suggests that riverine vegetation was stable from 9,000-2,000 BP which would have made the canyon bottoms a more attractive habitation for human settlement than the less stable plateaus and mountainous areas.

The phytolith record does not fully support the 'Oasis effect' because there was a steady shift in vegetation to a more restricted woodland component from 6,000 BP to the present as well as an increasing presence of mesic vegetation that peaked by 3,500 BP.

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Chapter 1: Introduction

1.1. Objectives of This Research

Over the last 20,000 years there have been major changes in global climate, reorganizations of physical environments and shifts in biotic communities. Past vegetation communities and climate changes have been studied in detail through pollen analysis (Hansen 1939; Mack *et al.* 1976, 1978, 1979, 1983; Mehringer *et al.* 1977; Barnowsky 1985; Whitlock and Bartlein 1997), geofluvial and geological research (Chatters and Hoover 1992; Davis 2001; Davis and Muehlenbachs 2001), and paleozoology (Guilday and Adam 1967; Martin and Gilbert 1978; Meatte 1986; Graham and Grimm 1990). Changes in climate and biotic communities had an important effect on archaeological records and influenced many facets of human life, from subsistence strategies to settlement patterns (e.g., Statham 1975; Ames 1991; Chatters 1995).

Environmental responses to climate change from the Late Pleistocene to the present would have affected human populations living in the Lower Salmon River Canyon, Idaho. Recently, Davis (2001) demonstrated that an accurate picture of climatic events in the canyon riparian zones could not be exclusively derived from mountain and plateau paleoenvironmental data. Through a number of proxies he found riparian vegetative communities responded in a non-linear fashion to climate changes. Based on these results he proposed an 'Oasis effect' in which floodplain vegetation is more closely linked to changes in groundwater than to climate (Davis 2001: 253). He predicted a lusher environment in canyon bottoms than those on canyon slopes, upland or mountainous regions. This riparian zone would have supported higher densities of plants and animals and this relative abundance of resources probably had a major impact on the settlement and exploitation patterns of early human populations in Idaho.

The goal of this project is to use phytolith analysis to determine paleovegetation conditions in the Lower Salmon River Canyon from full glacial time to the present. In addition, this is a test of the relative stability of vegetation cover since deglaciation as predicted by Davis' (2001: 253) 'Oasis effect.' In the phytolith record, any such stability would be manifested as a largely homogenous vegetation population with no major shifts through time (e.g. from C_3 to C_4 grassland, from grassland to forest). Sixty-three sediment samples were collected from exposures at Lyons Bar (SR-26A and SR-26C) and Hammer Creek (SR-23) and analysed for phytoliths. These sediment sections were selected for several reasons. Radiocarbon dates indicate they span the period of time in question. Additionally, the sediment profiles had been previously sampled for grain size and stable isotope data in order to establish paleoclimatic record for the Lower Salmon River Canyon (Davis 2001). This will be a useful comparison for phytolith data.

To date, little paleoenvironmental work has been done along the Lower Salmon River. Phytolith indicator morphotypes are used here to interpret past climatic fluctuations from full glacial times to the present. Data are compared to other paleoenvironmental records from the same area, and are set in a wider, regional context.

1.2. The Oasis effect

Archaeologically, Idaho shows evidence of human occupation as early as 12,000 BP (Butler 1986; Davis 2001). Sites were generally small, low-density scatters of artifacts, suggesting short habitation events and a highly mobile settlement pattern (Chatters and Pokolylo 1998; Ames *et al.* 1998). Populations were initially small, with site distributions being largely a factor of seasonal environmental productivity (Ames 1988). Sites have been found at all elevations and locales on the plateau but their distribution suggests a preference for more intensified use of mesic areas (Ames 1988). This settlement pattern was probably developed to better exploit a seasonal resource base of high variability and low reliability. The pattern persisted until ca. 9,000 BP, after which site distributions along the Lower Salmon River indicate extensive seasonal hunting and gathering (Roll and Hackenberger 1988). The introduction of plant processing tools and changes in land use suggest upland hunting (see Davis 1987) and plant resource procurement along with intensified habitation in the river canyons. Over the first half of the Holocene, initially low population densities increased and resources were utilized more intensely (Holmer 1989; Plew 1990). By 5,500 BP pithouses appeared in the river valleys of the southern Columbia Plateau (Ames 1991). Over the following millennia, there was a trend towards decreased population mobility as well as increased density and complexity of pithouse structures, especially noticeable after 2,000 BP (Hackenberger *et al.* 1987; Ames 1991; Chatters and Pokotylo 1998). A broad based economy exploiting large game, intensified salmon fishing and use of collectable roots, and the development of storage technology have been proposed as the major contributing factors to the establishment of semisedentary communities on the Columbia Plateau (Lohse and Sammons-Lohse 1986). By the time of European contact, populations had settled into a pattern of partial or full sedentism (Ames and Marshall 1980). Historically, the /nimuputimt/ (Nez Perce) inhabited the southern Columbia Plateau. Their settlement system was largely an adaptation to physiographic heterogeneity and the resulting diversity of plant and animal communities (Marshall 1977).

Davis (2001) noted a non-linear biotic response to climate and geomorphic conditions in the Lower Salmon River Canyon from the Early Holocene through the Middle Holocene (ca. 9,000-2,000 BP). He went on to suggest that, during this time, riparian floodplain vegetation responded less to climatic influences and more directly to changes in groundwater levels. This 'Oasis effect' resulted in a stable, lush, riparian environment very different from the conditions found on canyon slopes, in the uplands and mountainous regions (Davis 2001: 253). The riparian environment probably supported higher densities of plants and animals making it an important and constant resource base for intensified prehistoric human settlement. This relative environmental stability and productivity would have been in contrast to adjacent canyon slopes and prairie plateaus that were becoming less productive and predictable. Davis (2001) argued that cultural changes between 9,000 BP and 2,000 BP resulted from choices hunter-gathers made to exploit the opportunities provided by Early Holocene riparian environments.

1.3. Evolutionary Archaeology and Darwinism

> "[The] primary goal of environmental archaeology should be to define the characteristics and processes of the biophysical environment that provide a matrix for and interact with socioeconomic systems, as reflected, for example, in subsistence activities and settlement patterns." (Butzer 1982: 6).

Butzer (1982) goes on to state that a subsidiary objective is to understand the human ecosystem as defined by the intersection of the biophysical environment and socioeconomic systems. Additionally, Dincauze (1987: 257) is of the opinion that environmental archaeology will be productive only if it is approached with the notion that "environmental determinism is neither the inspiration nor the goal" of such research.

Butzer (1982) provided a coherent and sound working theory based on the union of archaeology and ecology. He used Darwinian reasoning as a way of explaining prehistoric socioeconomic changes and proposed that socioeconomic systems, as part of ecosystems themselves, emerge partly as a social response to sets of ecological opportunities for exploitation (Butzer 1982). In other words, environmental effects on human populations are mediated through cognition and technology, or more specifically through adaptation (Dincauze 1987). Human adaptations to ecological opportunities lead to internal (social) and external (environmental) adjustments, some of which are 'successful,' resulting in demographic expansion, and others are 'retrograde,' resulting in demographic contraction (Butzer 1982: 314). The Darwinian approach has been further developed by many authors and has resulted in two major trends in recent archaeological theory, these being evolutionary archaeology and evolutionary ecology.

As per Davis' (2001) model for Lower Salmon River Canyon paleoecology, this study will interpret data in the framework of Darwinian concepts.

> "Evolutionary archaeology has many parallels to modern paleobiology and is geared to providing Darwinian explanations of the archaeological record like those offered by paleobiologists for the paleontological record. It involves building cultural lineages and then constructing explanations for those lineages." (Lyman and O'Brien 1998: 616).

The basic tenet of evolutionary archaeology can be summarized as follows: selection works most directly on the manifestation of a response to a need, that is the result of innovation, and not necessarily on innovation itself. In other words, culture change is explained as the action of selection and other evolutionary processes (e.g., variation and transmission), on heritable variation in artifacts and behaviour (Boone and Smith 1998). By demonstrating that particular human behaviours enhance fitness, an explanation for those behaviours becomes apparent (Lyman and O'Brien 1998). Thus, culture change arises from 'adaptive decision making' as a response to an external or internal stimulus. For example, the exploitation of one resource over others is a result of selection for such action, as that behaviour is adaptive to the needs of the particular group of people. Selection is a process which is both probabilistic and optimizing, meaning it is not a force to achieve optimality but is one to select for suitability (Mithen 1989; Lyman and O'Brien 1998).

Darwinian concepts and environmental archaeology are effective tools for understanding the influence of landscape history [i.e., the physical/ economic/ political/ social and historical influences (Muir 1999)] on culture and the subsequent manifestation of this in the material culture record.

1.4. The Value of Phytolith Studies

Butzer (1982: 28) identified five 'orders' of scale changes in ecosystems. The first and second are the 'small scale variability' of year to year and/or cyclic variations lasting up to a decade in length. Third and fourth order scale changes are described as a state of dynamic equilibrium with major perturbations or 'low threshold equilibrium shifts' lasting for centuries to tens of millennia (Butzer 1982: 28). Fifth and sixth order changes are any which are larger and of longer duration such as continental movement or variations in the Earth's orbital parameters.

Phytolith research is ideal for studies of third, fourth and fifth order magnitude. The nature of sediment deposition does not allow for distinguishing smaller order scale changes because chronological resolution is not on a fine enough scale. Phytoliths preserve well except under extreme conditions. They allow for the identification of taxa to varying degrees of specificity. As will be discussed later, phytolith assemblages have been shown to be representative of vegetation communities. This enables the researcher to identify plant communities over long periods of time and follow changes through differing representations of diagnostic morphotypes.

1.5. Comment on Thesis Structure

This chapter has reviewed the theoretical standpoint which will be a base for this thesis. The following chapter is a literature review of paleoenvironmental and archaeological studies in the region. This will be used to frame the interpretations of phytolith data from this study. Also, a background of the study area is provided as an outline of the modern and prehistoric landscape of the Lower Salmon River Canyon. Chapters 3 and 4 review theoretical and methodological processes which are necessary for understanding the nature of the phytolith record and for interpretating phytolith data. Results from this study are presented in Chapter 5. Chapter 6 provides a summary of this study. Appendices have been added to provide the raw data, detail the use and calculations of appropriate statistical tests and to provide the maximum relevant information in order to make this thesis as useful for future researchers as possible.

This thesis will not only provide information on phytolith research in the Lower Salmon River Canyon but also be a useful review of phytolith methods and theory, Pacific Northwest archaeology and paleoenvironments as well as statistical applications to phytolith studies.

Chapter 2: Environment and Culture on the Columbia Plateau

2.1. Physiographic Regions of the Study Area

A physiographic province is a large area of land having surficial features and topographic relief that can, at least tentatively, be demarcated from adjacent regions (Rhodenbaugh 1939; Atwood 1940). The study area for this project is situated on the boundary of two physiographic provinces: the Columbia Plateau and the Northern Rocky Mountains.

The Columbia Plateau is composed of a series of nearly horizontal lava sheets, ranging from 3 m to 60 m thick, which have been folded and faulted to create a flat or gently rolling terrain (Fenneman 1931). These lava beds are interrupted by irregular mountainous protrusions and deeply incised canyons (Hunt 1974). This makes the general character of the Columbia Plateau a broad uplift of minor ranges, basins, plateaus and uplands marked by local warping and faulting and effected by erosion (Plate 2.1) (Freeman *et al.* 1945).

Today, the Plateau's climate is semi-arid due to the proximity of the Cascade Mountains and the rain shadow they create. The Columbia Plateau is subdivided into the Columbia Basin, Central Mountains, High Lava Plains and the Owyhee uplands (Figure 2.1) (Freeman *et al.* 1945).

The Central Mountains subdivision, in which most of the study area is located, is a complex group of mountain ranges and dissected uplands. Most surfaces are composed of deformed and eroded lava beds and associated sedimentary deposits (Freeman *et al.* 1945). Three ranges or sub-provinces make up the Central Mountains (Figure 2.2). The Blue Mountains are a complex group of mountain ranges and dissected highlands. The Seven Devil's section consists of two mountainous uplifts separated by a lower lava plain and the Snake River (Plate 2.2) (Freeman *et al.* 1945). The TriState Uplands sub-province is distinctly lower than the Central and Seven Devil Mountains and is a continuation of the eastern Columbia Basin subdivision. High altitude warped lava beds, deep canyons and few sedimentary characters have left

Plate 2.1. The Lower Salmon River Canyon (view upstream, photographed by Brad Somer, 2001).

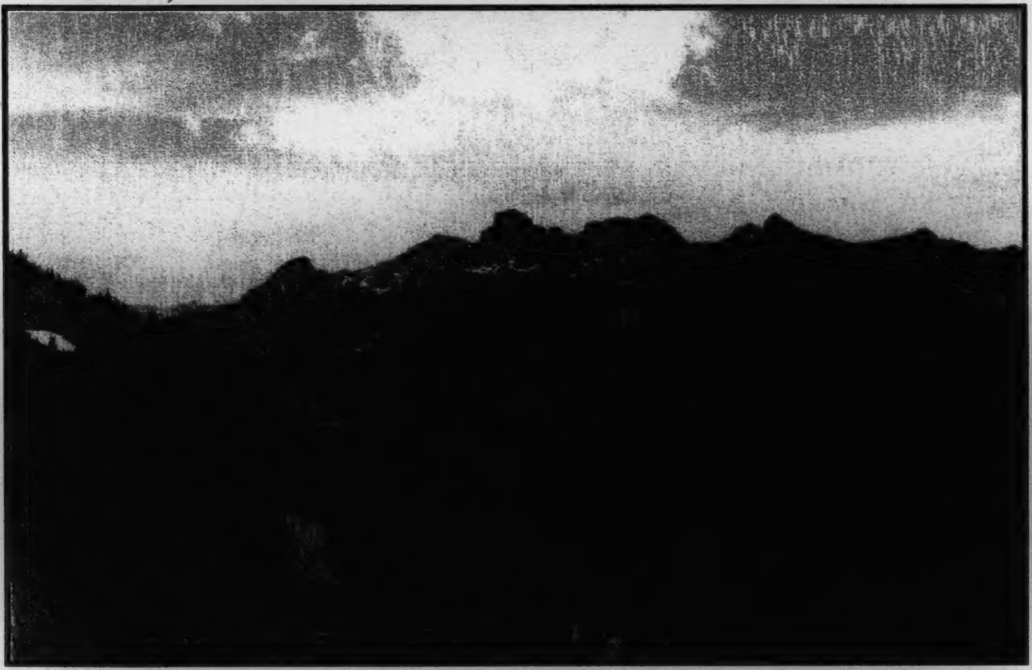


Plate 2.2. The Seven Devils Mountains (view south, photographed by Brad Somer, 2001).

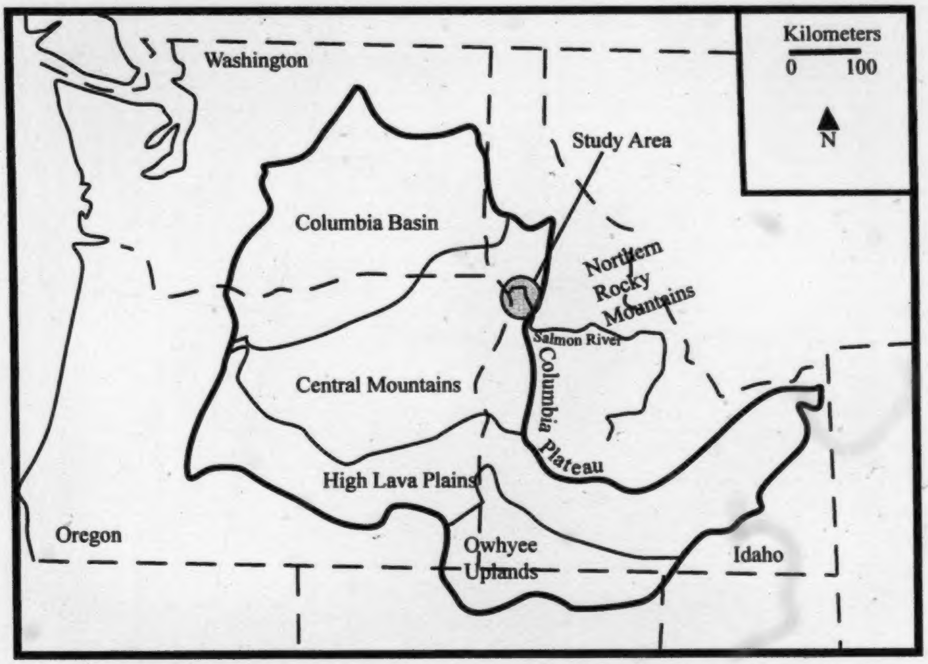

Kilometers
0 100
N
Washington
Study Area
Columbia Basin
Northern Rocky Mountains
Salmon River
Central Mountains
Columbia Plateau
High Lava Plains
Oregon
Owhyee Uplands
Idaho

Figure 2.1. Physiographic regions of the Columbia Plateau (adapted from Freeman *et al.* 1945).

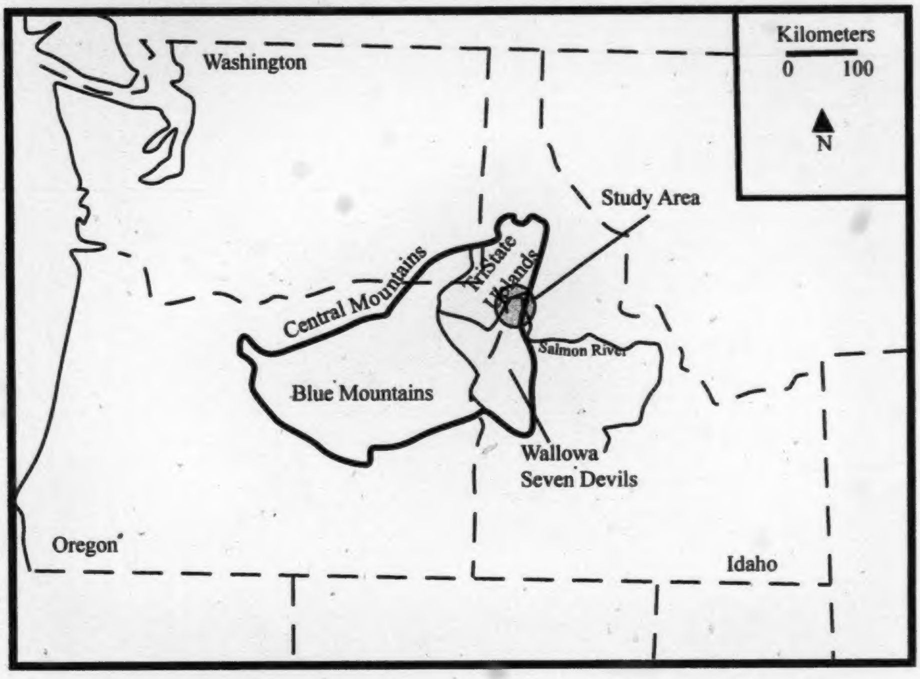

Kilometers
0 100
N
Washington
Study Area
Central Mountains
Tristate Uplands
Salmon River
Blue Mountains
Wallowa Seven Devils
Oregon
Idaho

Figure 2.2. Physiographic subprovinces of the Central Mountains (adapted from Freeman *et al.* 1945).

this sub-province with gently rolling uplands that are deeply incised by the Clearwater, Salmon, Snake and Grande Ronde rivers (Plate 2.3). The headwaters of the Salmon River, in the Bitterroot Mountains of central and east Idaho, exist 3,100 m above sea level. The Lower Salmon River Canyon bottom is around 500 m above sea level. In the immediate area of this study, the land is typified by deep, relatively wide canyons sectioning rolling upland prairies. The canyons are as much as 500 m lower in elevation than the surrounding plateau.

The Northern Rocky Mountain physiographic region covers much of central Idaho. This region consists of deeply dissected mountain ranges that are 600 m higher than the Columbia Plateau (Hunt 1967). The Salmon River drains the Salmon and Bitterroot Mountains of the Rockies.

The study area for this project is physiographically diverse. Within a relatively restricted area, there are drastic changes in altitude, highly variable plant and animal communities, and numerous microenvironments. This diversity is key in understanding the archaeological and paleoenvironmental records.

2.2. Environmental History

In discussing the nature and effects of environmental change one must first address the issues of temporal and geographic scale. The latter has been described in the previous section. To gain as complete a picture of climatic events as possible it is necessary to obtain regional and even global information.

Climate operates on many temporal scales. These range from annual cycles, such as seasons, to larger ones operating over hundreds of thousands of years, such as those involving the Earth's orbital motions. These cycles influence climate on different geographic scales. They may affect a lake's water level, regional vegetation or even global atmospheric circulation. Phenomena resulting in large scale cycles include: cyclical changes in Earth's orbital path (Petit *et al.* 1999) and resulting fluctuations in the amounts of solar radiation reaching Earth (van Geel *et al.* 1999) as well as other influences such as variation in oceanic circulation (Broecker 1997). Recent evidence

Plate 2.3. The Salmon River at Hammer Creek (view downstream, photographed by Brad Somer, 2001).

suggests that teleconnections in earth-ocean-atmosphere play an important role in controlling things like continental climatic regimes and even drought cycles. An example of this is the El Nino phenomenon, which has recently been proposed to be a major driving factor for events such as drought in North America (Nemanishen 1998).

2.2.1. The Modern Environment

The Lower Salmon River Canyon is located in what Gould and Shaw (1983) call the 'Palouse Prairie.' C_3 grasses such as *Agropyron spicatum* (bluebunch wheatgrass), *Festuca idahoensis* (Idaho fescue) and *Poa secunda* (Sandberg's bluegrass) are major components of this grassland (Kuchler 1964; Wright and Bailey 1982). The occasional *Artemisia tridentata* (sagebrush) are also found.

Agropyron spicatum was the most important and widespread original grass cover with *Festuca idahoensis* being restricted to higher elevations. This vegetation community has changed recently under the influence of cultivation and heavy grazing practices. Introduced C_3 grass species like *Bromus tectorum*, *B. japonicus* and other annuals like *Artemisia tridentata* are now quite prominent (Gould and Shaw 1983). Drainages usually exhibit stands of various shrub species [e.g., *Celtus douglasii* (hackberry)], *Pinus ponderosa* (Ponderosa pine) and *Pseudotsuga menziesii* (Douglas fir) with the latter two species being dominant in mountain ranges and at higher elevations surrounding the canyons (Kuchler 1964).

Precipitation falls mainly in the winter between November and February (Gould and Shaw 1983). At Grangeville, Idaho, the closest upland weather station to the study area, mean annual rainfall between 1948 and 2000 was 60.5 mm and mean annual snowfall was 124.2 mm (Table 2.1). Similarly, records for Cottonwood (1950 through 2000) show an average rainfall of 57.2 mm and snowfall of 86.4 mm. Both of these weather stations are located on the prairie plateau of the Tristate Upland (Figure 2.3). A canyon bottom site upstream from these stations at Riggins (1940 through 2000) indicated 42.7 mm of precipitation as rain and 18.5 mm of snowfall annually (Western Regional Climate Center 2001). There is little rainfall from June through

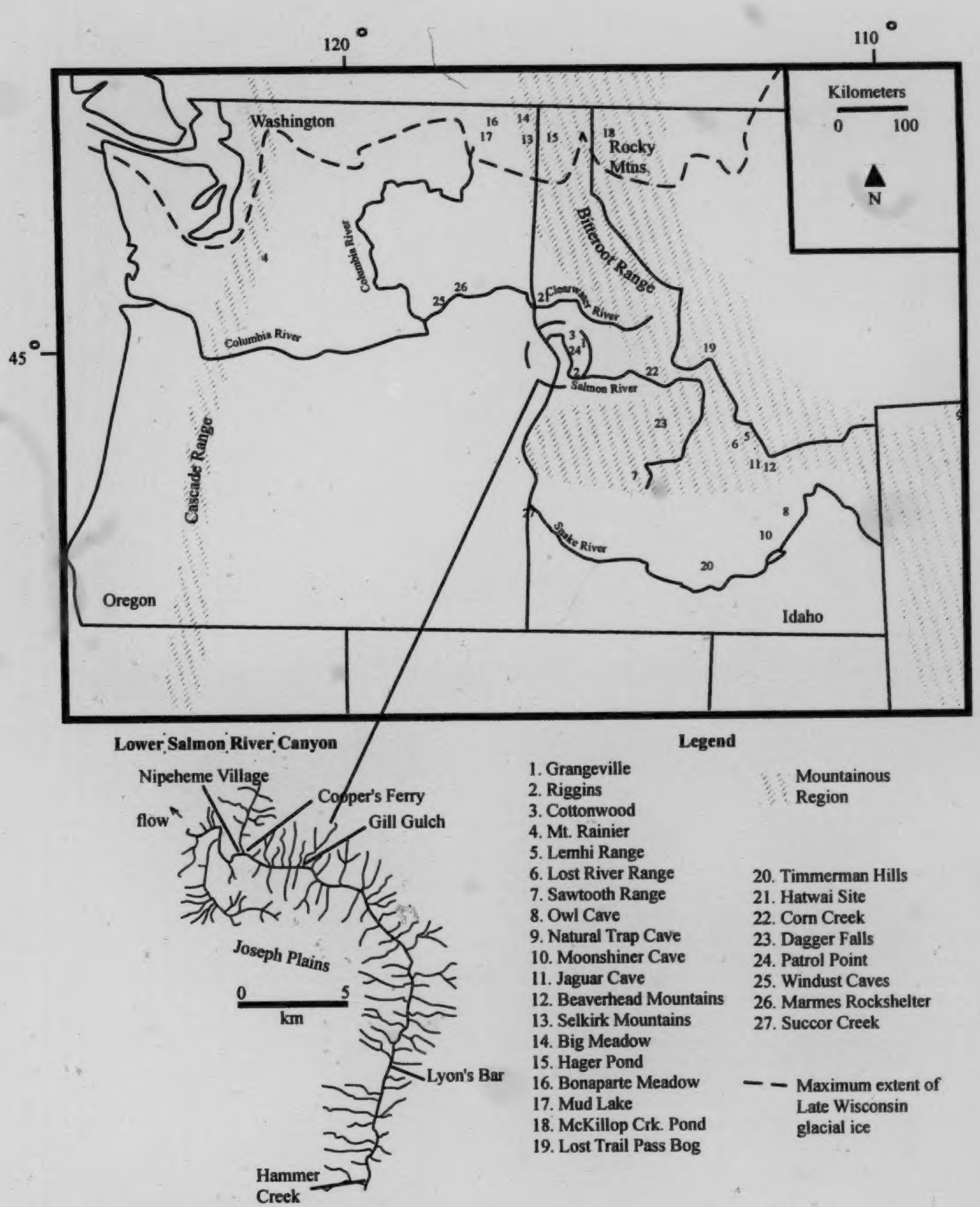

120°
110°
Kilometers
0
100
N
45°
Washington
Rocky Mtns
Bitteroot Range
Columbia River
Columbia River
Clearwater River
Salmon River
Snake River
Cascade Range
Oregon
Idaho
Lower Salmon River Canyon
Nipeheme Village
Cooper's Ferry
Gill Gulch
flow
Joseph Plains
0
5
km
Lyon's Bar
Hammer Creek
Legend
1. Grangeville
2. Riggins
3. Cottonwood
4. Mt. Rainier
5. Lemhi Range
6. Lost River Range
7. Sawtooth Range
8. Owl Cave
9. Natural Trap Cave
10. Moonshiner Cave
11. Jaguar Cave
12. Beaverhead Mountains
13. Selkirk Mountains
14. Big Meadow
15. Hager Pond
16. Bonaparte Meadow
17. Mud Lake
18. McKillop Crk. Pond
19. Lost Trail Pass Bog
20. Timmerman Hills
21. Hatwai Site
22. Corn Creek
23. Dagger Falls
24. Patrol Point
25. Windust Caves
26. Marmes Rockshelter
27. Succor Creek
Mountainous Region
Maximum extent of Late Wisconsin glacial ice

Figure 2.3. Locations of sites mentioned in text.

August. With most moisture coming from snowmelt, grass production is typically quite good in the earlier part of the year, followed by a period of summer dormancy due to aridity, and winter dormancy due to low temperatures (Gould and Shaw 1983).

Recorded temperatures vary between upland and canyon bottoms (Table 2.1). Two upland records, one from Grangeville and the other Cottonwood, show mean annual temperatures to be cooler than canyon bottom temperatures, recorded at Riggins, about 50 km upstream from the study sections (Western Regional Climate Center 2001).

Table 2.1. Summary of modern environmental data (adapted from Western Regional Climate Center 2001).

Station	Rainfall (annual mm)	Snowfall (annual mm)	Mean annual high (°C)	Mean annual low (°C)
Grangeville	60.5	124.2	10	1
Cottonwood	57.2	86.4	13	3
Riggins	42.7	18.5	19	5

Today, climates in this area are surprisingly mild despite the high latitude and altitudes. The vegetation cover is predominantly grassland. Although water stress is a limiting factor for larger plants, various shrub and tree species do survive in drainages, around springs, in sheltered areas and along some north exposures.

2.2.2. Glaciation

The distribution of plant and animal species, along with features of the physical environment have both been directly influenced by glaciation (Menzies 1996). Two ice sheets dominated the land surface in North America: the Cordilleran and the Laurentide. Together they covered most of Canada as well as the northern and western portions of the United States. These massive ice sheets and the enormous volumes of melt water they produced scoured the countryside, flooded valleys, choked rivers and streams with sediment and created a foundation for the modern landscape of northern North America.

Climate deterioration at the end of the mid-Wisconsin interstadial may have begun as early as 29,000 BP (Clark *et al.* 2001). This caused the Cordilleran ice sheet to advance from centers in British Columbia. It terminated just south of, what is today, the international boundary. Cordilleran ice created a nearly continuous sheet from the Pacific Ocean to the continental divide. This is evident from the positions of terminal moraines, out-wash bodies and other indicative geomorphic features. Unfortunately, end moraines are typically devoid of datable material and therefore glacial chronologies are usually inferential.

The Purcell Trench Lobe of the Cordilleran ice sheet penetrated Idaho to approximately 48°N latitude (Figure 2.3). Ice filled the Purcell Trench to the west of the Bitterroot Range and blocked the Clark Fork River drainage creating a basin in which glacial Lake Missoula was formed (Waitt and Thorson 1983). There is evidence of at least forty separate filling and draining events of this glacial lake. Complementary rhythmic slack-water sediments are evidence for these flooding events on the Columbia River and its tributaries (Waitt and Thorson 1983). The maximum southward extent of the ice had been reached some time between 22,000 and 18,000 BP during the 'Spokane Glaciation' (Waitt and Thorson 1983).

By ca. 11,000 BP, the North American ice sheets had retreated north of, what is today, the international boundary (Waitt and Thorson 1983). While this was the last time there was continental glaciation in the area, there is evidence for alpine glacial readvances. The glacial chronology of the Salmon River Basin is poorly understood in comparison to other areas in the Pacific Northwest (Davis 1988; Davis 2001).

Glacial advances on Mt. Rainer, Washington are dated between 13,320 and 12,880 BP and then again at 9,900 BP. Mt. Rainier does not show glacial readvances during the Younger Dryas, a cold period best known from Europe and the North Atlantic area where it is dated between 11,000 and 10,000 BP. The Younger Dryas is evident in many other areas of the Pacific Northwest as well as other parts of North and South America (Osborn *et al.* 1995). It is probable that the rain shadow effect in conjunction with prevailing climatic factors resulted in a cold-arid environment in the Cascade Mountains and the adjacent Columbia Plateau during the Younger Dryas (Heine 1989). This would account for a colder period with no ice formation.

In the mountainous regions surrounding the Columbia Plateau, the Rocky Mountains to the east and the Cascade Mountains to the west, topography played a major role in the distribution of glacial deposits and vegetation. Idaho was subjected to alpine glaciation during and after the Pleistocene epoch (Dort 1965). These glaciers were typically less than fifteen kilometers long at their maximum extent. Glacial deposits at high elevations (Table 2.2), show evidence for multiple stages of mountain glaciation. Unfortunately these advances and retreats have not been adequately dated.

Table 2.2. Extent of glacial deposits in study area (adapted from Dort 1965).

Location of Deposits.	Location Description.	Lower Limit of Wisconsin Ice.
45°30'N/ 115°30'W	Buffalo Hump Area, Idaho County.	1,525m.
45°N/116°30'W	Seven Devils Area, Adams County.	Below 1,525m. Small glaciers to 2,130m, most above 1,830m.
45°30'N/115°30W	Dixie Area, Idaho County.	Above 2,130m.
45°30'N/116°W	Florence Area, Idaho County.	To 1,675m, locally to 1,220m.
45°30'N/116°W	Warren Area, Idaho County.	To 1,675m, rarely at 1,220m.
45°30'N/116°W	Secesh Basin, Idaho County.	To 1,830m. 1,220m nearby. Cirques above 2,285m.
46°N115°30'W	South and Middle forks of the Clearwater River, Idaho County.	To 1,070m forming Piedmont glaciers.

Local climates controlled the relative timing and distance of alpine glacial advances from valley to valley and during the different stages of glaciation. While most mountain ranges were clear of glacial ice by 11,200 BP, there were some Holocene readvances. Glaciers in the Lemhi and Lost River ranges readvanced around 7,500 BP (Davis 1988). During the Pinedale glaciation, there is evidence for alpine glacial advances in the northern Rocky Mountains with glaciers existing as low as 2,300 m (Dort 1962). In the Lemhi Mountains, some Bull Lake Glaciers extended beyond the later Pinedale glaciers (Dort 1962). The Little Ice Age (LIA), ca. AD 1500 to AD 1850, saw glaciers advance to 2,900 m in this same area. Few glaciers remain in Idaho today; only small ones are present at elevations over 3,100 m in the Sawtooth and Lost River Ranges of the Rockies (Davis 1988).

Data from archaeological sites have also helped to delimit cold periods and frozen ground. On the eastern Snake River plain, Dort (1968) and Butler (1969) found several levels of what they interpreted as ice wedge casts during excavations at Owl Cave (10BV30). Later investigations determined that these were actually desiccation cracks, indicating times of increased aridity (Charles Schweger, personal communication). The deepest and largest cracks have been dated to 14,000 BP. Other arid events have been found dating to 8,160±260 BP and 7,750±210 BP, one between this period and 6,600 BP, and yet another shortly after 6,600 BP (Dort 1968; Butler 1968).

Although glacial chronologies in the Lower Salmon River headwaters are poorly understood, it is evident from surrounding areas that there were numerous periods of flux. While the Lower Salmon River Canyon itself was not covered by glacial ice, higher altitude glaciation and out-wash from glacial ice masses played a role in its history. As will be discussed later, these fluctuations would have had a substantial impact on local vegetation, human settlement and animal communities.

2.2.3. The Faunal Record

Faunal remains from sites such as Natural Trap Cave, northern Wyoming, and Jaguar Cave, Idaho, offer a picture of Late Pleistocene ecology. Prior to 10,000 BP the faunal assemblage at Natural Trap Cave was composed primarily of large mammals, many now extinct, the herbivores of which very likely fed on open steppe vegetation (Martin and Gilbert 1978). By 10,000 BP the faunal assemblage showed a more homogenous composition thought to result from an expansion of prairie and deciduous forests. Animals such as *Bison* and *Antilocapra*, that are better adapted to grasslands, become abundant and widely distributed at this time (Martin and Gilbert 1978).

A microfauna assemblage has been recovered from deposits dating from 7,000 to 11,580±250 BP in Jaguar Cave. This is a small cave, located at an elevation of 2,250 m in the Beaverhead Mountains (44°17'N/112°35'W), which is at the lower limit of Pleistocene glaciation (Guilday and Adam 1967). The faunal assemblage associated with the early date is dominated by *Camelops*, *Equus*, *Panthera atrox* and *Dicrostonyx torquatus* (collared lemming). The microfauna records an absence of arboreal or woodland taxa, except *Martes americana* (marten) which today inhabits talus slopes as well as woodland areas. Additionally, animals represented in the assemblage presently have more northerly ranges. No animals that currently live south of the cave were found (Guilday and Adam 1967). The presence of *Dicrostonyx torquatus* (collared lemming) and *Lagurus curtatus* (sagebrush vole) in the fossil assemblage is important. These were the two most common small mammals in the Jaguar Cave assemblage and are now extirpated in Idaho (Guilday and Adam 1967). These species presently have an allopatric distribution; *Dicrostonyx torquatus* is an obligatory tundra form with a long boreal climate evolutionary history, and *Lagurus cutatus* is now found only in the brushy plains of the dry interior north of 50°N latitude (Guilday and Adam 1967). Consequently, the small mammal assemblage from Jaguar Cave suggests a cold, tundra/steppe like environment during Late Pleistocene times.

Caribou in Idaho are now restricted to portions of the Selkirk Mountains in the Northern Panhandle (Meatte 1986). During the late Pleistocene (10,370±350 BP) however, archaeological evidence shows their range extended well south into the Snake River Plain (Meatte 1986).

From the examples above, it is obvious that there have been significant changes in the distribution and composition of animal species in Idaho. In the Late Pleistocene, 12,000 years ago, the presence of large mammals and cold adapted species suggests a period of cooler temperatures and a more tundra or steppe-like environment. Late Quaternary warming caused species to move along environmental gradients in different directions and rates depending on their individual climatic tolerances (e.g., the collared lemming; Graham and Grimm 1990).

2.2.4. Fluvial Response to Changing Environmental Conditions

Fluctuating environmental conditions since Late Pleistocene times have had an impact on the behaviour of rivers and drainage systems in the Rocky Mountains and the Columbia Basin. Fluvial responses to climatic change have been diverse and largely dependent upon geographic location (Baker 1983). Fluvial changes in the Late Pleistocene and the Holocene have been evaluated by making inferences from contemporary relationships between sediment yield, carrying capacity, surrounding vegetation, and water volume. Regional differences in river action are largely representative of adjustments to conditions of climate and vegetation.

Generally, periods of high sediment yield can lead to aggradation and can arise from glacial melt water sources, rising sea level and changes in the precipitation/ evaporation regime (Baker 1983). During the last glacial period and throughout the initial deglaciation, upstream areas near glacier margins likely had melt water streams choked with glacial sediments that filled valleys and built broad floodplains. Incision occurred during the interglacial period when there was reduced glaciofluvial sediment loads (Matsch 1976).

Since the last full glacial episode, the Columbia River drainage basin has undergone several episodes of terrace building (alluviation) and subsequent river entrenchment. Chatters and Hoover (1992), found evidence for three episodes of flood plain aggradation followed by periods of channel entrenchment (Table 2.3). The first major period of aggradation likely began between 9,000 and 8,500 BP and lasted until ca. 6,850 BP (Chatters and Hoover 1992). The second episode of aggradation began around 4,400 BP and lasted for roughly one thousand years (Chatters and Hoover 1992). The final episode of aggradation occurred with the establishment of the modern flood plain. Based on dates from archaeological occupations, the flood plain appears to

Table 2.3. Changes in river activity since deglaciation.

	Columbia River Drainage (Chatters and Hoover 1992)	Lower Salmon River (Davis 2001)
	Downcutting.	Aggradation.
2,000 BP	Construction of modern floodplains, rapid alluvial fan development.	Downcutting.
	Channel downcutting, gradual eolian accretion on floodplains.	Relatively constant aggradation.
4,000 BP	Formation of terraces, aggradation.	
6,000 BP	Channel downcutting slow floodplain accretion.	
8,000 BP	Terrace development.	
	Low sedimentation rates.	Sporadic floodplain development.
10,000BP	No record.	
12,000BP		No record.

have been formed around 2,400 BP and stabilized by 1,800 BP (Chatters and Hoover 1992).

In the Columbia River system, of which the Salmon River is a part, Chatters and Hoover (1992) discuss aggradational episodes, glacial readvances, depositional events, archaeological evidence and palynological data in an attempt to infer temperature and precipitation regimes. The earliest flood plain deposition event follows inferred climate change from cooler temperatures with spring precipitation to warm temperatures and winter dominant precipitation. The second aggradational event, beginning in 4,000 BP, seems to be at the transition from warm, arid conditions to cooler and wetter conditions. They suggest that deposition of the modern flood plain began after a change from a cold, moist climate to one of drier summers and warmer winters. Winter dominant precipitation at moderate rates, with warmer winter conditions typically leads to more severe flooding (Chatters and Hoover 1992). Increased winter precipitation would have moved sediments from shallowly frozen grounds leading to greater sediment loads and deposition in the Columbia drainage system.

In the Lower Salmon River Canyon, floodplain development was sporadic between 11,400 and 8,500 BP as a result of fluctuating climatic conditions and/or local geomorphic effects (Davis 2001). This was followed by a period of persistent alluviation except for a period of down cutting ca. 2,000 BP (Table 2.3) (Davis 2001).

In summary, river activity in this region influenced by a number of factors, from amount of ground cover to precipitation/snow melt to geomorphic processes. While determining the precise causes of aggradation and degradation remains problematic, definite events of floodplain construction and incision are apparent for the Lower Salmon River Canyon.

2.2.5. Palynological Data

Palynology is the most prevalent source of Quaternary paleoenvironmental information. While it is excellent for regional interpretations of vegetation communities, it does not offer a fine enough temporal or geographic resolution to distinguish small-scale heterogeneities (Beaudoin 1993, 1999). Additionally, palynologists in the Pacific Northwest have looked exclusively in the mountainous regions of Oregon, Washington and Montana for such information. Lower elevation records are not available.

There have been no palynological studies done in the immediate area of the Lower Salmon River. The following summary of paleoenvironmental studies therefore will rely on regional sources. It is important to realize that trends may manifest themselves differently at various altitudes, microenvironments and geographic locations as many sites discussed here are ca. 400 km from the Lower Salmon River.

Pollen records from the time of full glacial conditions are rare. In the Colorado Rocky Mountains, pollen studies record a tree line depression of over one thousand meters between 21,000 and 14,000 BP. It has been calculated, by combining precipitation gradients with traditional lapse rates, that this would result from a drop in mean summer temperature of about 7°C from present values (Porter *et al.* 1983).

In the Pacific Northwest, Mack *et al.* (1978a) cored a mire in Big Meadow, Pend Orielle County, Washington. The mire is at an elevation of 1,040 masl and was covered by Cordilleran ice during the last glacial maximum. It therefore is a record of vegetation development following deglaciation (Mack *et al.* 1978a). The Big Meadow core (Table 2.4) indicates low influx rates during deglaciation. A predominance of *Artemisia* and Poaceae, along with minimal pine pollen suggests predominantly non-arboreal vegetation cover. This is interpreted as a tundra-like landscape that persisted until roughly 9,700 BP. An increase in diploxylon pine pollen (i.e., *Pinus ponderosa*) and a decrease in grass from 9,700 to 3,300 BP reflected the development of pine forest with a perennial grass under-storey. This would have occurred under conditions warmer and slightly drier than the present. There was a short climatic reversal at 3,300 BP, during which *Picea* and *Abies* became predominant. This indicates a cooler and moister environment from that 9,700 to 3,300 BP. (Mack *et al.* 1978a). Around 2,400 BP conditions started to trend towards present day conditions (Mack *et al.* 1978a).

Table 2.4. Summary of regional palynological records for the Pacific Northwest.

	Lost Trail Pass Bog (Mehringer *et al.* 1977)	McKillop Creek Pond (Mack *et al.* 1983)	Big Meadow (Mack *et al.* 1978a)	Hager Pond (Mack *et al.* 1978b)	Mud Lake/Bonaparte (Mack *et al.* 1979)
	2,152m	920m	1,040m	860m	1021m
	Haploxylon pine pollen dominates. Modern type vegetation.	Initiation of modern upland vegetation. *Tsuga heterophylla, Abies* and *Picea* present. Diploxylon pine makes up majority of pollen influx.	*Tsuga heterophylla* levels high. Pine, *Pseudot./Larix* remain prominant. *Alnus* continus decline. *Picea, Abies* less prominant. NAP rare. Initiation of modern vegetation.	*Tsuga heterophylla* period. Sharp increase in *T. hetero. Abies* also prominant.	Diminished *Artemisia* after 6,700 years BP. Rapid change at this point to a diploxylon pine dominant cover with *Pseudotsuga menziesii* becoming prominant. Change to modern vegetation.
				Noticible increase in pollen influx of *Picea, Abies, Pinus. Artemisia* and Gramineae are minor contributions. (cool/moist)	
	Pine and spruce pollen increase in abundance. *Pseudotsuga/Larix* decrease. (cool/moist)				
2,000BP					
			Picea, Abies and diplo. pine prominant. *Tsuga heterophylla, Pseudot./ Larix* important. *Alnus* decline. (cool/mst)		
		Resurgence of *Abies* and *Picea. Pseudotsuga/Larix* become prevalant. *Pinus* increases. (cool/moist)			
				Pseudotsuga, diplox. pine and *Artemesia* abundant. Decreasing amounts of Gramineae coincide with increase in *Artemisia. Abies, Picea, Pseudotsuga/ Larix* are frequent. (warm/dry)	
			Diploxylon pine dominant pollen type. Decreasing importance of grasses. *Abies, Pseudotsuga/Larix* remain minor. Appearance of *Tsuga heterophylla. Picea* becomes more conspicuous. (warm/dry)		
4,000BP	*Pseudotsuga/Larix* locally abundant. Lower pine and spruce values. (warm/dry)	Diploxylon pine pollen rises to prominance w/ a decline in *Artemisia* and Gramineae. *Pseudotsuga/Larix* become prevalant. NAP is sparse. (warm/dry)			
					Rapid increase of *Carex* at start of zone. Increased *Artemisia,* decreased *Pinus. Artemisia* dominant w/ large grass component. Presence of diplo. pine pollen. (warm/dry)
6,000BP					
	Pinus forest. *Artemisia* pollen [illegible]ls dramatically. *Abies* migrates into the area. (cool/moist)	High *Artemisia* pollen. Less pronounced increase in Gramineae. (warm/dry)	*Pinus* increases. *Pseudotsuga/Larix* appears. Gramineae and *Artemisia* still important. Increase *Abies* and *Picea. Alnus* becomes important contributor. Pine forest with perrenial grass understory. (warm/dry)		Largely *Artemesia,* Gramineae with rare diploxylon pine pollen. Greater influx of NAP than previous. Rare *Picea* and *Abies.* Absence of *Pseudotsuga/Larix.* (warm/dry)
				Gramineae predom. Less *Pinus.* Increase NAP. (warming/drying)	
8,000BP					
				Abundance of diplo. pine, *Abies, Picea.* Low *Artemisia* and Cyper. (cool/moist)	
				Low influx rate. Low *Artemisia* and Cyperaceae. Abundance of diplo. pine, *Abies, Picea.* (cool/moist)	
			High percentages of Gramineae and *Artemisia* with low pine, *Picea* and *Abies.* Low influx rate. Cyperaceae, Cheno/Amaranthaceae found almost exclusively. (cool/moist)		
					Haploxylon pine, *Artemisia,* Cyperaceae, and Gramineae predominate. Low pollen influx rate. Minor tree component. (cool/moist)
10,000BP					
		Predominantly arboreal pollen. Haployxlon pine with conspicuous *Abies* and *Picea.* Minor amounts of *Artemisia,* grass, Compositeae and Chenopods. (cool/moist)			
	Artemisia and Gramineae dominant in steppe type environ. (cool/moist)				
12,000BP	No data				
			No data		

Mack *et al.* (1978b) also studied a pollen core from Hager Pond, Bonner County, Northern Idaho. This site is located at an elevation of 860 masl, a few hundred meters lower than Big Meadow Pond and the core covers >9,500 BP to the present. The five-stage pollen sequence here is similar to the pollen stratigraphy at Big Meadow (Table 2.4).

Assemblages from 9,500 to 8,300 BP were dominated by diploxylon pine with low percentages of *Abies*, *Artemisia* and *Picea*. There was a low pollen influx rate through this interval, and *Artemisia*, Cyperaceae and Poaceae comprised a small percentage of the core (Mack *et al.* 1978b). SEM provided identification of *Pinus albicaulis* (whitebark pine), *P. monticola* (western white pine) and *P. contorta* (lodgepole pine). The presence of white bark pine suggests a cooler and moister climate as this is a vegetation type similar to that now found at higher elevations. It is probable that these results reflect an elevation depression of taxa during the glacial and immediate post-glacial periods (Mack *et al.* 1978b).

Between 8,300 to 7,600 BP, increased presence of *Pseudotsuga menziesii*, *Artemisia* and diploxylon pollen denotes a change in vegetation and continuation of warm and dry conditions which persisted until 3,000 BP (Mack *et al.* 1978b). This indicates that the cool climate was rapidly replaced by warmer, drier conditions. After this point in time, an increase of *Picea* and *Abies*, and diploxylon pine indicates a reversal of climate to cooler and more moist conditions which persisted until 1,500 BP at which time a modern vegetation pattern becomes apparent, dominated by *Tsuga heterophylla*.

Cores from Mud and Bonaparte Lakes, Okanagan Valley, Washington, yielded records dated to 11,000 BP (Table 2.4) (Mack *et al.* 1979). As the glaciers retreated, *Artemisia* and haploxylon pine dominated plant invasion on newly exposed ground. Mack *et al.* (1979), believe that this is indicative of cool, moist conditions and probably steppe vegetation.

Beginning around 10,000 BP, pollen of diploxylon pine and *Artemisia* increased in frequency suggesting that the climate grew progressively warmer and drier. *Artemisia* dominated in the Okanagan valley until about 5,000 BP. By 4,700 BP there was an abrupt increase in the amount of *Pinus* pollen. Mack *et al.* (1979) interpreted this as the establishment of modern vegetation in the area (*Pinus* and *Pseudotsuga menziesii*). There is a rather abrupt decrease of *Artemisia* representation in the pollen record during this time. The record from Mud and Bonaparte Lakes does not provide evidence for the reversal to a cooler, moister environment after the warmer stage as seen between 3,300 to 2,400 BP in the Big Meadow and Hager pond studies (Mack *et al.* 1978a, 1978b). Mack *et al.* (1979) attribute this to differences in latitude, topographic position and differing hydrology between sites.

McKillop Creek Pond and Tepee Lake, northwestern Montana, are two other high altitude sites, both over 920 masl (Mack *et al.* 1983). They exhibit subdivisions similar to those of the Big Meadow and Hager Pond cores (Table 2.4). Prior to 11,000 BP, there was an abundance of arboreal pollen, namely *Pinus*, *Abies* and *Picea*, and low percentages of non-arboreal pollen, particularly *Artemisia* and Poaceae, indicating a cooler and moister climate than today's (Mack *et al.* 1983). Low pollen influx and highly inorganic sediments indicate the paucity of terrestrial vegetation in this zone (Mack *et al.* 1983). Between 11,000 and 7,100 BP an increase in *Artemisia* and a less marked increase of Poaceae was noted but pine pollen still constituted the largest component of the pollen record. Mack *et al.* (1983) suggest that this resulted from a warming trend and that the ground cover was largely treeless, open vegetation; dominated by *Artemisia* and grasses with scattered stands of pine trees. Between 7,100 and 4,000 BP there was a decline in non-arboreal pollen and *Pinus* pollen rose to prominence again. This indicates prominent forests and a return to cooler and more moist conditions than the previous subdivision, but suggests that the vegetation reflects an environment which was warmer and drier than the present at this elevation (Mack *et al.* 1983). There was a resurgence of *Abies* and *Picea* from 4,000 BP until about 2,770 BP which is thought to reflect a waning of the warmer drier conditions of the middle Holocene in favour of a moister and cooler climate (Mack *et al.* 1983). From this point on, there is an initiation of modern upland vegetation with characteristic *Tsuga heterophylla* (hemlock), *Abies* and *Picea*.

Lost Trail Pass Bog (2,152 masl) in the Bitterroot Mountains of Montana spans the last 12,090 years (Mehringer *et al.* 1977). It is located in a small, forested depression left in the wake of glacial retreat. By 12,000 BP, glacial ice had withdrawn and sagebrush steppe dominated the landscape, indicated by abundant *Artemisia* and grass pollen (Table 2.4). At 11,500 BP, *Artemisia* and grass dominance was replaced abruptly by pine-dominated forest (Mehringer *et al.* 1977). These cooler than present conditions persisted until 7,000 BP. From 7,000 to 4,000 BP, *Pseudotsuga-Larix* became locally abundant at the expense of pine and spruce suggesting a warming trend (Mehringer *et al.* 1977). At 4,000 BP, *Pseudotsuga-Larix* was no longer as common and pine and spruce values increased indicating a return of cooler climates. From 4,000 BP onward there has been little change in the pollen record.

From the pollen sequences discussed above, one is able to gain a good idea of regional post glacial vegetation changes from the Late Pleistocene to the Holocene. Indeed, there is correlation between the five sequences in the nature and timing of changes on a macroenvironmental scale (Table 2.4). Big Meadow and Hager Pond shared similar climatic changes in a five stage, synchronous record. Comparison of pollen assemblages from these sites at significantly different altitudes provides evidence of elevation depression of taxa during and immediately following glaciation.

During glacial times and at the onset of glacier retreat, higher elevations were predominantly steppe-like with ground cover consisting mainly of *Artemisia*, grasses and haploxylon pine species. At this time there was a low pollen influx rate suggesting open vegetation with only a minor tree component. This reflected conditions cooler and moister than today. These types of vegetation commonly occurred in areas vacated by glacial ice. It may have taken considerable time for the ground to thaw and conditions to become suitable for pioneer plant species to invade. Initially, groundcover would have been sparse and steppe- or tundra-like (see Mott and Jackson 1982; Hickman and Schweger 1996 for example).

At the same time, at lower elevations, arboreal taxa were the most important pollen contributors. Diploxylon pine species, *Abies* (fir) and *Picea* (spruce) were dominant. There was a smaller percentage of *Artemisia*, *Cyperaceae* and Poaceae pollen than seen at higher elevations. This is likely representative of fairly well forested ground cover. This type of vegetation was subsequently seen at higher elevations as the climate became milder.

In the pollen records the effects of deglaciation were seen ca. 11,500 BP. A warming trend brought pine forests with perennial grass/*Artemisia* understories to higher ground. Meanwhile, a predominant grassland environment established itself at lower elevations.

At higher altitudes, around 7,000 years ago one sees a continuation of the warming trend. At some higher sites, the warming trend was associated with an increase in moisture as diploxylon pines, *Tsuga*/*Pseudotsuga* and *Picea* became more conspicuous in the pollen record. During this period, there was a continuing and persistent warming trend which had been initiated during the previous phase. At lower elevations, a grassland environment persisted with *Artemisia*/Poaceae pollen being dominant.

Between ca. 4,000 and ca. 3,000 BP, depending on the location, a cooler and moister climate regime affected vegetation patterns. Mixed forests with a prominent pine component became established with an associated increase in *Picea*/*Abies*. These conditions persisted until between 2,500 and 1,500 BP, at which point the climate and resulting vegetation trended towards modern conditions.

Establishment of modern vegetation is seen in other regional palynological records with variable timing and some minor differences (Hansen 1939; Mack *et al.* 1976; Barnowsky 1985; Whitlock and Bartlein 1997).

2.2.6. Paleoentomological Data

A record of paleotemperatures has been extrapolated from extensive work on fossil beetle assemblages of the Northern Rocky Mountain region. Elias (1996) used Mutual Climatic Ranges of 20 fossil beetle assemblages to calculate paleotemperatures for eleven sites, two from Montana, one from Utah and the remainder in northern Colorado. Ages of the sites ranged from 14,500 to 400 BP. A Mutual Climatic Range

(MCR) was obtained for all beetles in the assemblage using modern climatic tolerances for beetle species to derive Quaternary temperatures (Elias 1996). MCR reconstruction yielded mean July temperatures to an accuracy of ±1°C and mean January temperatures to ±3°C (based on modern comparisons) (Elias 1996). The results are summarized in Table 2.5. As with the palynogical data from the previous section, it is important to realize that trends may manifest themselves differently due to local geographic influences. The closest paleoentomological assemblages are ca. 500 km east of the Lower Salmon River Canyon requiring these data to be considered in a more regional setting.

The fossil beetle record is considered to be a responsive measure of temperature because the predatory species of beetle used typically react to changes in temperature with a lag time of less than 150 years (Elias 1996). From these data, the 10,000 BP summer insolation maximum was evident as a drastic swing from conditions colder than the present to significantly warmer (Figure 2.5). After this, there was a gradual cooling to modern temperatures.

Table 2.5. MCR temperatures from fossil beetles of Northern Rocky Mountains (adapted from Elias 1996).
(Temperatures are departures from present day temperatures for the region).

Age (10^3 BP)	July temperature (°C from present)	January temperature (°C from present)
3.0 – present	Modern.	-
7.8-3.0	Equal - 2 degrees warmer.	-
9.0	1-4 degrees warmer.	Slightly cooler than modern.
10.0	4-7 degrees warmer.	6-10 degrees warmer.
13.2 – 12.8	3-4 degrees cooler.	19-21 degrees cooler.
14,500	10-11 degrees cooler.	26-30 degrees cooler.

2.2.7. Isotope and Grain Size Analysis from the Lower Salmon River

The $\delta^{18}O$ signature of soil carbonate is an indicator of meteoric water composition. As ^{16}O evaporates preferentially, an increase in the $\delta^{18}O$ represents more arid conditions. In other words, ^{16}O would be evaporating to a greater extent than heavier oxygen isotopes, leaving higher concentrations of the heavier ^{18}O isotope in soils. The $\delta^{13}C$ signature also derived from soil carbonate is related to relative proportions of plants having a C_4 photosynthetic pathway. A decrease in $\delta^{13}C$ values reflects more temperate conditions because there are fewer C_4 plants in the community (Amundson *et al*. 1988).

Davis (2001) and Davis and Muehlenbachs (2001) conducted paleoenvironmental investigations in the Lower Salmon River Canyon. Davis (2001) constructed a high resolution Late Pleistocene to Holocene record of terrestrial climate and vegetation in riparian areas of the Lower Salmon River Canyon employing oxygen and carbon stable isotopes, and sediment grain size analysis (Table 2.6). Prior to 21,000 BP, Davis (2001) documented an oscillating decline in $\delta^{18}O$ values and fluctuations between C_3 and C_4 grass community components. The coldest period occurred immediately after 21,000 BP, the full glacial. The Late Pleistocene was characterized by an arid period at the beginning of deglaciation followed by a return to a cooler climate. By 11,000 BP, a warming/drying trend is evident. The Early Holocene was characterized by a stable vegetation composition despite broad swings in $\delta^{18}O$ values (Davis 2001). From the Middle Holocene to the present a cooler and more moist climatic regime developed, punctuated by a seemingly more arid phase beginning 2,000 years ago (Davis 2001).

Davis and Muehlenbachs (2001) used $\delta^{18}O$ values from *Margaritifera falcata* (river mussel) shells found in three archaeological sites (Cooper's Ferry 10IH73, Gill Gulch 10IH1308, and Nipeheme Village 10IH1312) to infer climatic conditions for different periods in Lower Salmon River climate history. The results of this study suggest numerous short-lived oscillations in temperature and precipitation regimes beginning with rather arid conditions in the Late Pleistocene and several Mid- to Late-Holocene fluctuations to a wetter climate (Davis and Muehlenbachs 2001) (Table 2.6).

Table 2.6. Isotopic data relevant to paleoenvironments of the Lower Salmon River.

	River Mussel Isotopic Data (Davis and Muehlenbachs 2001)	Isotopic and Grain Size Data (Davis 2001)
	Modern conditions.	Sharp rise in 13C and low 18O see onset of drier conditions.
	Wettest period.	
2,000 BP	Wetter but gradually becoming drier.	All ^{13}C values decrease, meaning fewer C_4 plants. Decreasing ^{18}O. Return to a wetter and cooler climatic conditions.
	Wetter (rapid change).	
4,000 BP	Rapid shift to more arid conditions.	
6,000 BP		Slopes and floodplains exhibit decreasing ^{13}C.
8,000 BP	Arid.	
	Wetter.	
	Arid.	Vegetative stability. fluctuating ^{18}O values.
	Wetter.	
10,000BP	Arid, driest period in this record.	^{18}O and ^{13}C rise, indicating warming and drying. Highest rate of fine sand sedimentation. Arid.
	Wetter.	
	Arid.	
12,000BP	No record.	
14,000BP		Decr. ^{18}O, colder climates.
		Incr. fine sand, incr. aridity.
16,000BP		
18,000BP		
20,000 BP		Oscillatory decline in ^{18}O composition. Fluctuating C_3 vs. C_4 plant dominance.

2.2.8. Insolation Records

The Milankovitch hypothesis states that variation in the geometry of the Earth's orbit governs seasonal insolation and therefore longer-term fluctuations in climate (Bennett 1990). The three variables driving major climate changes are: precession of the equinoxes (a 21,000 year cycle in the Earth's equinoxes), obliquity (a 41,000 year cycle in the tilt of the Earth) and eccentricity (a 100,000 year cycle of change in the shape of the orbit) (Figure 2.4) (Hays *et al*. 1976). Eccentricity is largely responsible for the amount of radiation reaching the Earth, while the other two variables are more influential in the latitudinal and seasonal distribution of this energy. As a consequence, the Earth has been subjected to these astronomical variations which altered climate on time scales of ~20,000 to 100,000 years and are thought to be largely responsible for the Quaternary ice ages (Bennett 1990).

The aforementioned orbital variations result in changes in the seasonal cycle of solar radiation reaching the Earth's surface (Figure 2.5). Between 12,000 and 6,000 BP, variations in seasonality were more extreme, with the broadest swings in the amount of solar radiation reaching the Earth's surface occurring between 10,000 and 9,000 BP. During this peak period, the amount of solar radiation was greatest in the summers of the Northern Hemisphere which would have caused increased summer temperatures. Kutzbach and Webb (1993) suggest a 5°C increase. It is also thought that winter temperatures would have been colder than the present as there was decreased radiation from December through February (Kutzbach and Webb 1993).

2.3. Summary of Environmental History

2.3.1. The Late Pleistocene

The Late Pleistocene saw two ice sheets; the Laurentide which initiated in Arctic Canada and the Cordilleran in the mountain ranges of British Columbia. Together, they covered nearly all of Canada and the northern portions of the United

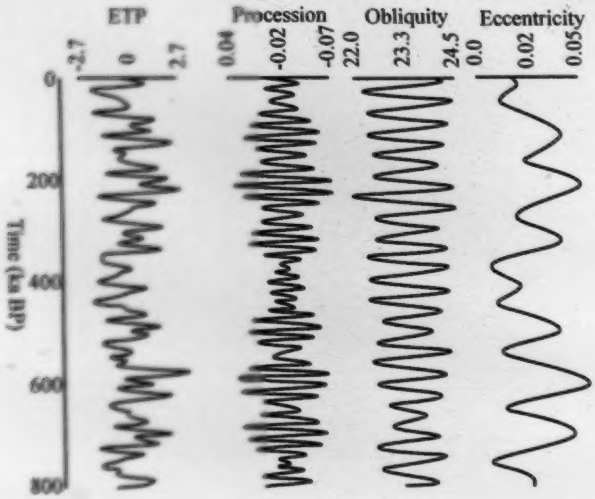


Figure 2.4. Milankovitch cycles over the past 800,000 years (adapted from Imbrie *et al.* 1984).

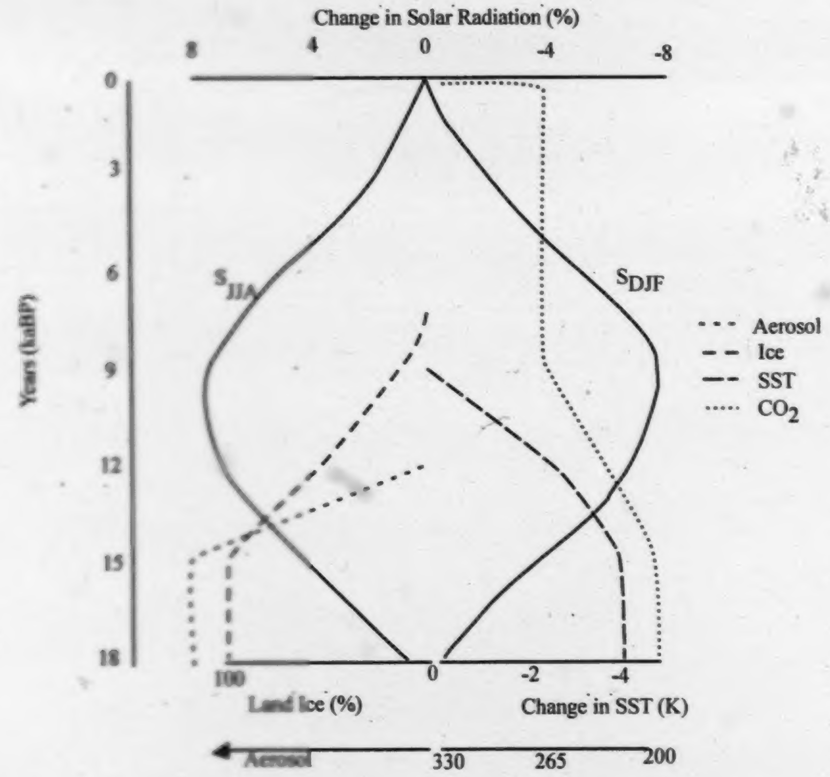


Figure 2.5. COHMAP simulation for the last 18,000 years (adapted from Kutzbach *et al.* 1993).

States. The Laurentide reached its maximum extent between 22,000 and 18,000 BP (Waitt and Thorson 1983; Lowe and Walker 1997). In British Columbia and Washington State, the Cordilleran was at its maximum extent between 15,000 to 14,000 BP (Lowe and Walker 1997). Along glacial boundaries and immediately after glacial retreat, vegetation was steppe-/tundra-like with most ground cover consisting of grasses, hardy species of *Artemisia* and only a few trees (Mehringer *et al.* 1977; Mott and Jackson 1982; Hickman and Schweger 1996). Cooler conditions caused altitudinal depression of species limits (see Table 2.3). For example, the lower altitude Mud Lake/Bonaparte site records pollen assemblages similar to later assemblages at the high altitude site of Lost Trail Pass Bog. Inferred paleotemperatures for the Northern Rocky Mountains ca. 14,500 BP suggest summer temperatures ~10ºC cooler than the present, while winters were 26° C to 30° C colder (Elias 1996).

In the Lower Salmon River Canyon during the Late Pleistocene there was an oscillating decline in $\delta^{18}O$ values indicative of cooling conditions (Davis 2001). Fluctuating $\delta^{13}C$ values suggest vegetation cover responding to several periods of punctuated arid and/or cooler periods through the Late Pleistocene. Isotope values around 14,500 BP indicate the beginning of a warming and drying trend (Davis 2001).

Glacial ice reached its maximum extent ca. 18,000 years BP. From this point, orbital perturbations resulted in increasing amounts of solar radiation reaching the Earth's surface (Figure 2.5). By the end of the Pleistocene, ice sheets, which had been covering large parts of the Earth's surface for more than fifty thousand years had largely disappeared (Lundqvist and Saarnisto 1995). As glaciers melted, drainages became choked with sediment causing a period of alluviation and floodplain construction.

2.3.2. The Pleistocene Holocene Transition

By 11,200 BP, much of North America including the northern United States Rockies, was ice-free (Davis 1988). This was a period of dramatic climate and biological change. Archaeological fauna assemblages suggest that by 11,000 BP conditions were suitable for cool climate animal species in Idaho. At higher altitudes and latitudes steppe-like conditions existed (Guilday and Adam 1967). From ca. 11,000 to ca. 9,000 BP, north west river systems went through sporadic periods of floodplain development (Chatters and Hoover 1992; Davis 2001). Paleotemperatures inferred from entomological data suggest that ca. 10,000 BP summer temperatures were 4°C to 7°C higher and winter temperatures 6°C to 10°C warmer than modern times (Elias 1996). This is the warmest period of Elias' records and is the period with the most extreme amounts of summer solar radiation reaching the Earth (Figure 2.5) (Kutzbach and Webb 1993). The nature of the flora suggests a warming and drying trend with *Artemisia*, Poaceae and Diploxylon pine pollen becoming important in a number of profiles.

Similar changes were seen in the Lower Salmon River Canyon as suggested by $\delta^{18}O$ and $\delta^{13}C$ values. A relatively stable, warm/dry climate existed prior to 11,000 BP with cooling by 10,000 BP (Davis 2001). For the next thousand years, the ratio of C_3 and C_4 vegetation was stable despite fluctuating moisture conditions (Davis 2001).

River mussel data also suggest that the transition period, ca. 11,000 to ca. 10,000 BP, was the driest seen in this record (Davis and Muehlenbachs 2001). The $\delta^{13}C/\delta^{18}O$ values from sediment samples and the highest rates of fine sand sedimentation in the canyon lead to similar conclusions (Davis 2001). All of this evidence suggests that the period between 11,000 and 10,000 BP was one of peak aridity and high temperatures (Elias 1996; Hickman and Schweger 1996; Davis 2001; Davis and Muehlenbachs 2001). However, these conclusions do not always agree with pollen data which suggest cooler/moister conditions. This apparent discrepancy could be attributed to the fact that there are many ecological factors affecting plant distribution making pollen analysis a complex proxy affected by the bioclimatic tolerances of many species.

2.3.3. The Middle Holocene

Palynological evidence indicates that the warm/dry trend initiated during the Pleistocene-Holocene transition continued into the Middle Holocene, although conditions were not as extreme. Paleoentomological temperature inferences suggest that at ca. 9,000 BP, summer temperatures were 1°C to 4°C warmer and winters were slightly cooler than the present. The solar radiation budget also suggests this trend, with more summer radiation and less winter radiation reaching the Earth than at present times (Figure 2.5) (Kutzbach and Webb 1993). There was a general cooling trend throughout this period until modern temperatures are reached ca. 3,000 BP. In addition, Lower Salmon River Canyon isotope data showed slowly declining $\delta^{13}C$ values, likely resulting from less C_4 flora and a gradual switch to cooler/moister conditions (Davis 2001).

The Lower Salmon River was in a state of relatively constant aggradation during this time (Davis 2001). This is different from the periods of alternating down cutting and alluviation seen in other areas of the Columbia River drainage system (Chatters and Hoover 1992). This difference is likely due to local variations in geomorphologic processes along this stretch of the river (Davis 2001).

2.3.4. The Late Holocene

Late Holocene climates were typically cooler and moister than the present. Palynological data indicate the initiation of cooler and moister conditions starting ca. 4,000 BP and persisting until ca. 2,000 BP. At this point pollen assemblages similar to modern ones suggest that modern vegetation was either established or becoming established.

After ca. 5,000 BP there is evidence of decreased C_4 plant abundance and lower $\delta^{18}O$ values, both suggestive of cooler and wetter conditions (Davis 2001). For the Lower Salmon River, most of this period is one of alluviation with a brief episode of down cutting ca. 2,000 BP (Davis 2001). At this time, there is also evidence for an increase in abundance of C_4 plants. Davis (2001) interprets this as a period when the water table dropped leading to restructuring of the plant community.

Between ca. 4,000 and ca. 2,000 BP, the region experienced conditions of increased moisture. This regional, wetter period is also seen locally in the Lower Salmon River Canyon. After 2,000 BP, there is a gradual drying until present conditions were reached. This also agrees with insolation patterns which show modern conditions were reached around this time (Figure 2.5).

2.4. Past Cultures and Previous Archaeological Research

2.4.1. Regional Outline

In 1961, Ruth Gruhn noted that the "state of Idaho was a blank spot on the archaeological map of the U.S." Since this time, much work has been done to uncover Idaho's past. Idaho has a blend of Great Basin, Plains and Columbia Plateau cultural traditions throughout its prehistory. The Columbia Plateau culture region is distinctive because of its diverse geographic character and aboriginal cultural adaptations to its unique resources.

Several regional chronologies have been developed for this area (Butler 1968, 1986; Roll and Hackenberger 1998; Ames *et al.* 1998). The following is a slightly modified version of Ames *et al.* (1998) and will be used as a framework throughout this thesis. A more detailed cultural chronology specifically for the Lower Salmon River Canyon will be discussed in subsequent sections.

2.4.2. Early Prehistoric Period >12,000 - 8,000 BP

Archaeologically, Idaho shows evidence of occupation as early, if not earlier than ca. 12,000 BP. Settlements in this period were sparsely distributed, small, low-density artifact scatters. This suggests short habitation events and a high degree of mobility. Populations were small, limited by the least productive season (late winter/early spring), with distribution being largely a factor of seasonal environmental productivity (Ames 1988). Tool kits were typified by leaf-shaped and stemmed points, ovate bifaces and assorted scrapers. Grinding implements were present and tools were generally expedient in nature (Chatters and Pokotylo 1998).

The first cultural tradition found in the material record is the Clovis tradition, which ranges from about 12,000 to 10,000 BP (Butler 1986). Davis (2001) provides evidence that a non-fluted technology (Lind Coulee points) on the southern Columbia Plateau was contemporaneous, if not earlier, than the Clovis tradition. Clovis culture artifacts have been associated with Pleistocene megafauna remains and are found all across the United States and into Mexico. Chief among the remains were mammoths (*Mammuthus* sp.), certain species of bison (esp. *Bison antiquus*), camel (*Camelops* sp.), horse (*Equus* sp.), mountain sheep (*Ovis* sp.), elk (*Cervus* sp.) and deer (*Odocoileus* sp.) (Butler 1986).

A number of Clovis finds have been made in Idaho (see for example, Potter and Aageson 1974; Woods and Titmus 1985; Petersen 1987; Titmus 1987; Titmus and Woods 1990). The Richey-Roberts Clovis Cache is the only known site in which Clovis material has been found in intact deposits; the rest have been surface finds. There is a higher frequency of finds in the southern and eastern portion of the state and this is thought to be a result of the proximity to the Great Plains where the early lanceolate tradition flourished (Huntley 1985). This could also be an effect of the disproportionate research focus in this state.

Folsom tradition artifacts have been found in the Timmerman Hills (Titmus 1985), along the Upper Salmon and the east fork of the Salmon River (also see Moe 1982). This tradition in Salmon River country is thought to span 11,000-10,600 BP (Butler 1986).

Eden points have been found at Succor Creek in southwest Idaho. They are thought to be part of the Cody Complex, a cultural complex of the High Plains. This complex is comprised of Eden, Scottsbluff, Alberta points and the Cody Knife (Mirau *et al.* 1999). Artifacts from this complex generally date between 8,800 and 8,400 BP in

Idaho (Green 1985). While not common in Idaho it offers an interesting link to the plains.

In summary, during the Early Prehistoric Period archaeological sites have been documented in all regions of Idaho from river valleys to mountainous uplands (Ames *et al.* 1998). All elevations and locales were apparently utilized. Site distributions suggest that the mesic areas (such as the canyon bottoms) were more intensively used than more xeric sites (Ames 1988). Highly mobile hunter-gatherers inhabited Salmon River country during this period. They hunted Pleistocene megafauna and later mammal communities, and likely engaged in opportunistic plant collection. Mobility was probably dictated by the seasonal availability of these main resources. Available archaeological data suggests a broad-spectrum adaptation from the initial settlement until about 8,000 BP (Chatters and Pokotylo 1998). As the artifact technology persisted over millennia, it would appear that across the Columbia Plateau this was a period of relative cultural stability (Ames 1988).

2.4.3. Middle Prehistoric Period 8,000 - 1,500 BP

There were marked cultural changes during this period such as the development of semi-subterranean pit houses and evidence for increased exploitation of salmon and nutritious roots (Chatters 1989; Ames *et al.* 1998). The appearance of large mortars, anvils and pestles on the Columbia Plateau lead some (Ames and Marshall 1980) to argue that certain root crops became important. Unfortunately, the majority of root collecting technologies are unlikely to be preserved in the archaeological record. Ethnohistorically, root diggers were made of wood or antler and root crops were collected in baskets (Downing and Furniss 1968). It is likely that root gathering and plant processing were important subsistence activities before evidence appeared in the archaeological record. In historic times, starting with the journals of Lewis and Clark and in later ethnographic reports, camas (*Camassia quamash*) was an important root crop for the people living in the southern Columbia Plateau.

From 8,000 to 4,000 BP subsistence activities focused on exploiting three main resources: large mammals, edible root crops and fish (typically anadromous salmonids) (Plew 1983; Chatters and Pokotylo 1998). The presence of anadromous fish in the major river systems provides an important basis for archaeological interpretation (Plew 1980; Lohse and Sammons-Lohse 1986). Site locations at the beginning of the Middle Prehistoric Period suggest upland hunting, and root and pine nut procurement (Roll and Hackenberger 1998). The increased number of sites also appear to have been more intensively used suggesting that low initial populations were increasing and resource intensification was taking place (see Holmer 1989; Plew 1990).

By the middle of the fifth millenium, sites were located in proximity to a stable and/or seasonally predictable resources (mussel beds, riverine fauna, large game, and plant crops) on alluvial terraces as well as uplands (Chatters 1995). Lohse and Sammons-Lohse (1986) consider this system of settlement to be sustainable through the increased use of salmonid fishing and root collection, and the continuation of large game hunting. Available evidence points to a widespread intensification of resource utilization in the Middle Prehistoric Period. At about this time, semi-sedentary villages appeared on the Columbia Plateau.

Binford (1990: 122) defined semi-sedentary as follows:

> "...a mobility situation in which relatively permanent base sites are maintained and returned to frequently, but where groups make seasonal forays from these hubs, moving their residential camps from place to place."

One of the features of semi-sedentary settlement on the Columbia Plateau was pit house structures. In the archaeological record, these are found as individual pits or clusters of pits. Initially, they were likely occupied for a short while before being abandoned. Typically house pits were located near the mouths of rivers or along trunk streams so that there was ready access to the river, stream, forest and steppe environments (Chatters 1989). This strategy allowed the use of as many different resources as possible and has been called 'edge effect' (Leopold 1933; Mirau 1990). The earliest pithouse structures in Idaho come from the Hatwai site in the central part of the state where they date to 5,550±120 BP (Tx-3262) (Ames 1991).

Ames and Marshall (1980), pose that intensification of root gathering was more important than fishing and seed collection because roots are highly predictable in their location and abundance and would have been available over extended periods of time. They suggest that this would have been the primary factor in the establishment of semi-sedentary communities. Undoubtedly the development of food storage technology would also have contributed greatly. Stands of camas become ripe with season and altitude, and harvesting could have started at low elevations and progressed to higher elevations. Salmon, on the other hand, while predictable, are only available for a short period of time during the year. A broad spectrum economy based on large game hunting, intensified root collection and salmon use, along with a change in settlement strategies to one of semi-sedentism were likely a response to environmental and social stimuli taking place during this period.

Between 4,000 and 3,000 BP the climate continued to cool and with less evaporative stress, fir/spruce/pine forests continued to expand (Chatters and Pokotylo 1998). There was a widespread appearance of pit houses at this time, with increased reliance on fishing, intensified root exploitation, and the development of storage techniques (Ames *et al.* 1998). Site distributions point to seasonal villages where the population over-wintered in the warmer valley bottoms. The spring was a time for fishing and plant collecting. A shift to the uplands and mountains in the summer and fall suggests the seasonal use of plant and animal resources in these areas. For example, the Dagger Falls site (10VY76) appears to have been a spring salmon fishing and fish processing site which was occupied periodically since 4,000 BP (Torgler 1993). These changes culminated in the ethnographic cultures of the region (Chatters and Pokotylo 1998).

Towards the end of the Middle Prehistoric Period there was a reduction in population mobility, with year-round occupation in the Middle Salmon River Canyon between 3,500 and 2,500 BP, and seasonal use of upland areas for hunting, gathering and hide processing (Chatters and Pokotylo 1998). There was also an increasing frequency, density and complexity of pit house structures especially after 2,000 BP (Ames 1991). Base camps were located on river bottoms and the settlement pattern became more complex and a more specified pattern of land use became apparent. Base camps served as winter residences in canyon bottoms. Seasonal field camps were scattered on plateaus and in mountainous areas to exploit specific staple foods and resources (Chatters 1995).

At Corn Creek, near the confluence of the Middle Fork and the Main Salmon River, early settlement occurred at 5,000 BP, after which there was a hiatus in occupation until 3,900 BP (Holmer and Ross 1985). Pit house features become common by 1,250 BP when the greatest density of artifacts is also recorded. Indeed, a general trend of increased intensity and duration of pit house occupation is seen across the Columbia Plateau over this time. There was a less selective distribution of camps along the waterways with seemingly no preference for the environmental edge placements as with earlier occupations (Chatters 1989).

Upland sites such as Patrol Point (10IH1603) occupied 2,000 years ago with predominance of projectile points, scrapers, bifaces and drills in the archaeological assemblage, indicate that hunting activities took place (Davis 1987). This suggests specialized sites for exploitation of specific upland resources.

2.4.4. Late Prehistoric Period 1500 - 250 BP

Leonhardy and Rice (1970: 17) commented that very little is known about the late Prehistoric Period relative to the others:

> "Knowledge about the prehistory of the Lower Snake River Region is unique in one respect: more is known about the earlier cultural manifestations than the later ones."

During this period there is the initiation of modern vegetation and floodplain development. Rapid flood plain formation in drainage basins indicates frequent flooding, which may have been due to greater availability of sediment from less densely vegetated uplands. Under these conditions alluvial fan formation also occurred (Chatters and Pokotylo 1998).

Starting at the end of the Middle Prehistoric Period and persisting well into the Late Prehistoric Period, there were greater numbers of pit houses in larger villages along the Salmon and Snake Rivers (Hackenberger *et al.* 1987). This probably indicates a life style of extended periods of sedentism, more so than was seen previously (Roll and Hackenberger 1998).

The annual cycle of movement in the Late Prehistoric Period has been called the "winter village" pattern (Ames and Marshall 1980). Winters were spent in the warmer valley bottoms. In the spring, the focus was on fishing and plant collection. As the year progressed, hunting replaced fishing in importance. Plant food resources were important at various times of the year depending on their seasonal availability. This is similar to the Desert Culture of the Great Basin and is generally considered a part of the larger "western village pattern" (Bettinger 1978; Ames and Marshall 1980). While the actual changes in prehistoric adaptive strategies manifested in the "winter village pattern" are not well defined, it has been attributed to intensification of fishing activities and plant resource utilization, as well as to innovation in food storage techniques (Lohse and Sammons-Lohse 1986).

2.4.5. Historic Period

Since the time of European contact, acculturation, as seen in the archaeological record, was extremely rapid. Iron objects are of special interest to archaeologists as they are evidence for European cultural contact. Metal tools typically are more durable and easier to repair, which could account for their rapid acceptance by native cultures (Crabtree 1968). Consequently, one specific indicator has been the change from stone to metal as a material for tool production. Metal tools have been found in several archaeological sites in Idaho (Plew 1987, 1989).

By the time of European contact, groups on the southern Columbia Plateau had settled into a pattern of partial or full sedentism (Ames and Marshall 1980). This is a continuation in the development of a seasonal pattern of settlement established during the Middle Prehistoric Period.

2.4.6. Ethnographic Settlement Patterns

Models of settlement patterns have developed largely in light of ethnographic data collected at the time of contact. At the time of Lewis and Clark's expedition through this area, the Nez Perce were the most numerous and powerful group in the Columbia Plateau (Sappington 1989). The European name for this group arose from the Shoshoni description of the "pierced nosed Indians" and later, Lewis and Clark noted the Nez Perce referred to themselves as *Cho pun-nish* or "Pierced Noses" (Sappington 1989). There is evidence for heavy reliance on plant gathering, hunting and fishing by the Nez Perce. Their settlement system was largely an adaptive strategy to physiographical heterogeneity and the resulting diversity of plant and animal communities (Marshall 1977). Seasonal availability of this wide resource base greatly influenced social organization. The settlement pattern was a product of social interaction (e.g., tenure restrictions in resource exploitation) and spatiotemporal distribution of various resources (Marshall 1977). Generally, a seasonal round took Nez Perce people from spring fishing and root collection in and around the canyons to later plant gathering and hunting on the plateaus and in the mountains. They lived in more or less isolated groups following a fairly regular seasonal round of activity.

Settlements were located to take advantage of resource availability. Winter villages were at lower elevations in deep canyons near water sources. They were usually situated at stream confluences near fishing locales and plant collecting areas. These were winter habitats and the time was spent on social interaction as well as on tool making and tool maintenance (Ames and Marshall 1980). Village locations were chosen with fresh water, wood, good drainage, and with easy access to upland areas in mind rather than for direct access to a particular resource. From late spring to early fall, the population dispersed, field camps on the region's plateaus were created and occupied to exploit specific resource locales. These camps were occupied with increasing intensity from March to June over periods of one and five days, long enough to exploit a particular resource (Ames and Marshall 1980; Binford 1980). Established pit house camps consisted of eight to twenty people and were more permanent. They tended to be along forest borders near root crop collecting areas. Small hunting camps were set up in the mountains specifically to hunt local game. Hunter groups would travel quickly and usually camped only overnight in any one location (Ames and Marshall 1980; Binford 1980).

2.6. Salmon River Culture Chronology

B. Robert Butler (1968) was the first to develop a cultural chronology for the Lower Salmon River Canyon. His preliminary chronology has recently been updated and revised by Davis (2001). To date, a large portion of work done on the southern Columbia Plateau uses the cultural chronology developed for the Lower Snake River Canyon of southeastern Washington by Leonhardy and Rice (1970).

2.6.1. Lower Salmon River Culture Chronology

Butler (1968) constructed a culture chronology for the Lower Salmon River based on excavations at five sites and the artifacts recovered therefrom (Table 2.7). Even though the chronology was criticized because it was based on a small number of sites, it has persisted. Davis (2001) reviewed the relevant literature and conducted further excavations and has proposed a chronology that makes use of Butler's original phases (with minor chronological changes) as well as two new, early phases called Cooper's Ferry I and Cooper's Ferry II (Table 2.7).

Table 2.7. Cultural chronologies for the Columbia Plateau.

Years BP	Ames *et al.* 1998 - Columbia Plateau	Leonhardy & Rice 1970 - Lower Snake River	Butler 1968 - Lower Salmon River Canyon	Davis 2001 - Lower Salmon River Canyon
Present	Late Prehistoric	Munipu Phase Piqunin Phase	Camas Prairie Phase	Camas Prairie Phase
1,000		Harder Phase	Rocky Canyon Phase	Rocky Canyon Phase
2,000	Middle Prehistoric		Grave Creek Phase	Grave Creek Phase
3,000		Tucannon Phase		
4,000			Craig Mountain Phase	Craig Mountain Phase
5,000		Cascade Phase		
6,000				
7,000				
8,000	Early Prehistoric			
9,000		Windust Phase		Coopers Ferry II
10,000				
11,000				Cooper's Ferry I
12,000				

The Cooper's Ferry I Phase spans the earliest part of the archaeological record in the Lower Salmon River Canyon, from 11,500 to 11,000 BP. The type-site for this Phase is Cooper's Ferry. At this time, there was limited occupation by people using a stemmed point technology (Davis 2001). In addition, thick flake unifaces and bifaces, multidirectional cores and modified expedient flake tools are characteristic of the assemblage.

The Cooper's Ferry II Phase lasted from 11,000 until 8,400 BP and was characterized by stemmed and lanceolate points similar to those of the Windust Phase (discussed in next section) (Davis 2001). Also present are scrapers made from large flakes and bifacially worked tools.

The Craig Mountain Phase was originally proposed by Butler (1968) and has been updated by Davis (2001). Characteristic artifacts were leaf shaped lanceolate points, antler wedges, and edge ground cobbles. Butler initially suggested dates from 7,400 to 3,500 BP, however Davis believes it spans 8,400 to 3,500 BP.

Butler's next phase, the Grave Creek Phase, lasted from 3,500 to 2,100 BP. It was delineated by increasing frequencies of Bitterroot type points and decreasing numbers of leaf shaped points. Grinding and milling stones were also seen from this Phase. Davis (2001) believes that the upper limit of this Phase is 2,000 BP and indicates a period of intensifying habitation of developing floodplains and alluvial fans.

The penultimate phase is the Rocky Canyon Phase, dated from 2,000 to 600 BP. This Phase marks the appearance of pit house structures and smaller, corner notched projectile points. Plant processing and fishing tools (e.g., net sinkers) increase in frequency.

The final phase is the Camas Prairie Phase extending from 600 to 150 BP. It was during this Phase that the ethnographic patterns of Nez Perce material cultural become apparent. Small basal and corner notched points, hopper and mortar bases, and desert side notched points were all common at this time.

2.6.2. The Lower Snake River Culture Chronology

Leonhardy and Rice (1970) organized artifacts into six cultural phases based on sites in the Lower Snake River, Washington, primarily on collections from Windust Caves and Marmes Rockshelter (Table 2.7).

The first phase is the Windust Phase, which spanned 12,000 to 9,000 BP. This earliest artifact assemblage included a variety of closely related projectile point forms with relatively short blades and straight or concave bases (Leonhardy and Rice 1970). It also contains large oval or lanceolate knives, and large, crudely made end scrapers. There was a wide variety of animal remains, but no salmon remains or evidence of plant food tools (Leonhardy and Rice 1970).

The next phase is the Cascade Phase. The lanceolate Cascade projectile point was characteristic in the Lower Snake and Lower Salmon Rivers for this period from 8,000 to 5,000 BP (Butler 1968; Leonhardy and Rice 1970). In addition, side-notched points, edge ground cobbles and the infrequent presence of manos and matates were features of this phase (Leonhardy and Rice 1970). This was a period of intensified resource utilization and increased population density. The late Cascade Phase was characterized by the appearance of the Cold Springs side-notched points which postdate the Mazama Ash fall. It also marked the first appearance of river mussels and large salmonids in faunal assemblages. No fishing tools were found in the archaeological assemblage even though it is obvious that this resource was exploited.

The Tucannon Phase bridged <5,000 to ca. 2,500 BP. The two dominant projectile point types had short blades, shoulders of varying prominence and contracted stems (Leonhardy and Rice 1970). Small end and side scrapers, and net sinkers were typical and there was also an increased frequency of plant processing tools. Utilized flakes were not as numerous as in previous stages. Salmonids and river mussels remained important economic species.

Leonhardy and Rice (1970) divided the third phase, the Harder Phase into two subphases based on settlement strategies. The Harder Phase I showed camp settlements, while during Harder II pit houses are first seen. This delineation is now irrelevant as further research has shown pit houses were present well before this time. The Harder Phase spanned 2,500 to 650 BP. Large basal and corner notched points, various scraper forms and cobble tools typified this Phase.

The Piqunin Phase, 650 to 250 BP, was the second to last phase. Small, finely made corner and basally notched points became frequent (Leonhardy and Rice 1970).

The final phase, the Numipu Phase, is a putative construction intended to reflect archaeological manifestations of the ethnohistoric period (defined as the time when the horse was introduced) (Leonhardy and Rice 1970). Some key artifacts include historic trade goods and metal projectile points.

Chapter 3: Theoretical and Methodological Approach to the Use of Phytolith Analysis in Paleoenvironmental Reconstruction

The use of phytoliths to describe ancient plant communities began in the early 1800's, but did not come into its own until the late 1900's. Today, phytolith analysis is used on its own and in conjunction with palynology and other paleoenvironmental proxies (see Witty and Knox 1964; Wilding and Drees 1968, 1971; Verma and Rust 1969; Yeck and Gray 1972; Carbone 1977; Fredlund 1993; Fredlund *et al.* 1998). Phytolith analysis is especially useful in situations where pollen has not been well preserved or in grasslands where palynology is not as helpful.

All photographs in the following sections (except Plates 3.21 and 3.24) were taken by the author of unpublished research materials prepared by, and with the permission of, Dr. Brian Kooyman, Department of Archaeology, University of Calgary.

3.1. The History of Phytolith Research

There has been much literature devoted to the history of phytolith analysis (see Piperno 1988; Powers 1992; Pearsall 2000). For this reason, the following is an abridgement highlighting only major developments and discoveries in phytolith history.

Christian Erhenberg, a naturalist to General von Minutoli on an 'antiquarian journey to Egypt,' extensively studied the flora and fauna of Northeastern Africa (Powers 1992). In 1830, he published a work on the identification, classification and distribution of microscopic plant and animal life in the region, termed *infusoria*. In this writing he first described *phytolitharia*, or 'plant stones.' A few years later (1835), the German botanist, Struve, observed phytoliths in living plant tissues.

Charles Darwin analysed phytoliths collected while aboard the H.M.S. *Beagle*. He noted:

> "Generally, the atmosphere is hazy and this is caused by the falling of impalpably fine dust, which was found to have slightly injured the astronomical instruments…I collected a little packet of this brown-coloured fine dust, which appeared to have been filtered from the wind by the gauze of the vane at the masthead…Professor Ehrenberg finds that this dust consists in great part of the infusoria with siliceous shields, and of the siliceous tissue of plants. In five little packets which I sent him, he ascertained no less than sixty-seven organic forms. The infusoria, with the exception of two marine species, are all inhabitants of fresh water." (Darwin 1845: 8)

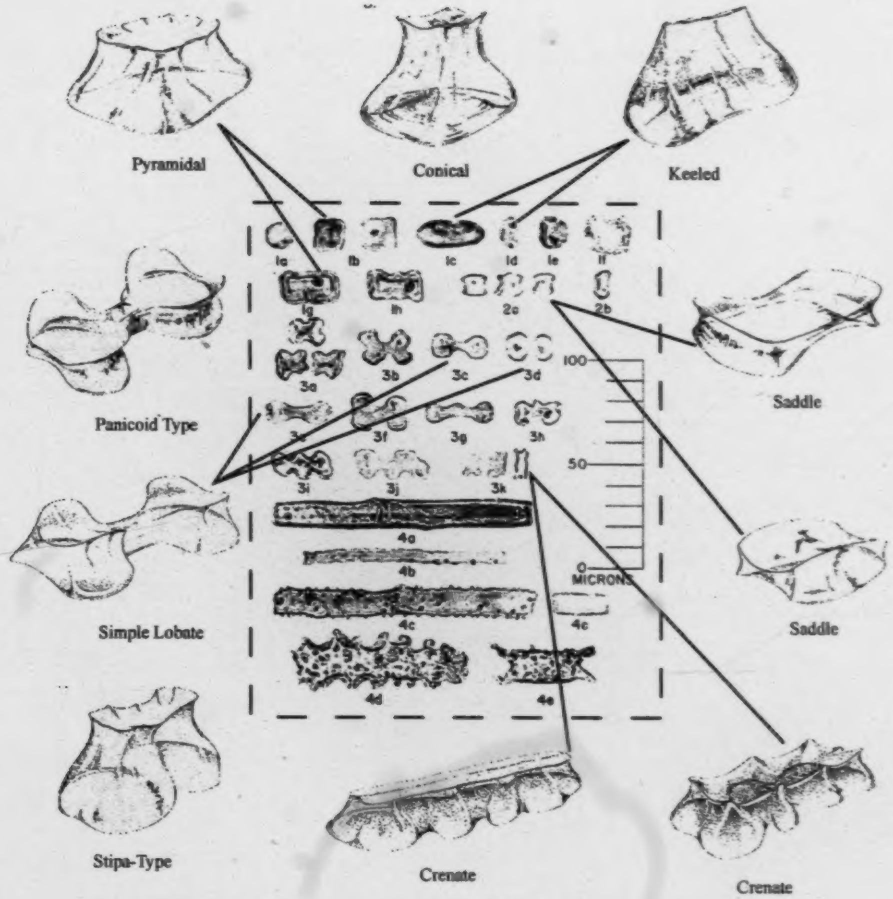
Initially, phytoliths were studied as soil constituents and aerosols. Research progressed through the beginning of the 1900's with the majority of studies published in German. Generally, these focused on isolating phytoliths in botanical samples and not their presence as discrete soil and dust entities (Piperno 1988). It was not until the 1950's that English-speaking scientists pursued phytolith studies with any degree of fervour. In North America, Parry and Smithson (1958) used phytolith bulliform cells as indicators for grasses and Jones *et al.* (1963) studied Holocene forest/prairie transitions. Problems arose as the body of data grew. Among the hurdles were issues such as phytolith redundancy, preservation and deposition. With time the focus shifted from methodological issues to data interpretation.

It was noted early on that woodlands and grasslands produce different amounts of opal phytoliths. This was the basis for pioneer paleoenvironmental works, which measured bulk phytolith composition to identify grassland/forest transitions (see Beavers and Stephen 1958). Research from the late 1960's to the early 1980's worked to refine bulk phytolith analysis by connecting specific morphotypes to known plant taxa. This allowed finer resolution in paleoenvironmental reconstructions. Work consisted mostly of classifying phytolith morphology and their association to different plant taxa. This resulted in the identification of many different 'diagnostic' phytoliths - those which were indicative of certain plants to some level of taxonomic specificity. Identification of grasses to the subfamily level is one example. While grass pollen from different taxa are indistinguishable from each other, phytoliths are not.

One of the seminal paleoecological applications of phytolith analysis was a study written by Twiss *et al.* (1969). They developed a classification system for distinguishing between the then three subfamilies of Poaceae (Figure 3.1). Chloridoid grasses (short grasses) produce the 'saddle shaped' phytoliths that Twiss *et al.* (1969) call 'chloridoid' (Plate 3.1). Panicoid grasses (tall grasses) create phytolith shapes such as 'dumbbell' (Plate 3.2) (today called bilobate) and cross-shaped. Festucoid grasses (grasses in humid regions) deposit phytoliths typically circular, rectangular, elliptical in shape or some variation of these shapes (Plate 3.3).

While Twiss *et al.* (1969) are praised for their work, their classification system is often criticized for its simplicity. In fact, as will be discussed later, classification of grasses and therefore grass phytolith classification is not straightforward. Many critics fail to mention that Twiss *et al.* (1969) were aware of problems with phytolith morphotype multiplicity and redundancy, and that their classification system was not all encompassing. They recognized that there were overlaps between subfamilies. For example, *Zea mays* (a panicoid) and *Aristida* (a festucoid) each produce both festucoid and panicoid types of silica bodies (Twiss *et al.* 1969). All grass subfamilies also produce an elongate class (epidermal quadrilaterals) of phytoliths (Plate 3.4) (Twiss *et al.* 1969). Not only did Twiss *et al.* study fossil phytolith assemblages, they also set up a series of 'dust traps' in Kansas and demonstrated that phytoliths in the atmospheric dust represent the surrounding modern vegetation (Twiss *et al.* 1969: 113). Their classificatory studies will be discussed further in section 3.3.3.

Palmer (1976) used the silica structure of grass cuticles as a paleoecological indicator in her study of African lake cores. Since grass pollen are largely taxonomically uniform and the area is dominated by entomophilous trees today, Palmer tested the suitability of phytoliths for distinguishing grasses in a paleoecological study. After extracting large cuticular fragments from the cores, phytolith shape, distribution and occurrence were used to identify grasses (Palmer 1976). She was able to identify and then link many cuticle fragments to the subfamily level, and using SEM determined the genus of specimens in numerous cases (Palmer 1976).


Pyramidal
Conical
Keeled
Panicoid Type
Saddle
Simple Lobate
Saddle
Stipa-Type
Crenate
Crenate
1a
1b
1c
1d
1e
1f
1g
1h
2a
2b
3a
3b
3c
3d
3e
3f
3g
3h
3i
3j
3k
4a
4b
4c
4c
4d
4e
100
50
0
MICRONS

CLASSIFICATION OF GRASS PHYTOLITHS

I) Festucoid Class
  1a. Circular
  1b. Rectangular
  1c. Elliptical
  1d. Acicular, variable focus
  1e. Crescent, variable focus
  1f. Circular crenate
  1g. Oblong
  1h. Oblong, sinuous
II) Chloridoid Class
  2a. Chloridoid
  2b. Thin Chloridoid
III) Panicoid Class
  3a. Cross, thick shank
  3b. Cross, thin shank
  3c. Dumbbell, long shank
  3d. Dumbbell, short shank
  3e. Dumbbell, long shank, straight or concave ends
  3f. Dumbbell, short shank, straight or concave ends
  3g. Dumbbell, nodular shank
  3h. Dumbbell, spiny shank
  3i. Regular, complex dumbbell
  3j. Irregular, complex dumbbell
  3k. Crenate

IV) Elongate Class (no subfamily characteristics)
  4a. Elongate, smooth
  4b. Elongate, sinuous
  4c. Elongate, spiny
  4d. Elongate, spiny with pavement
  4e. Elongate, concave ends

Figure 3.1. Grass short cell phytolith morphotypes (boxed portion adapted from Twiss *et al.* 1969 and surrounding morphotypes from Fredlund and Tieszen 1994).

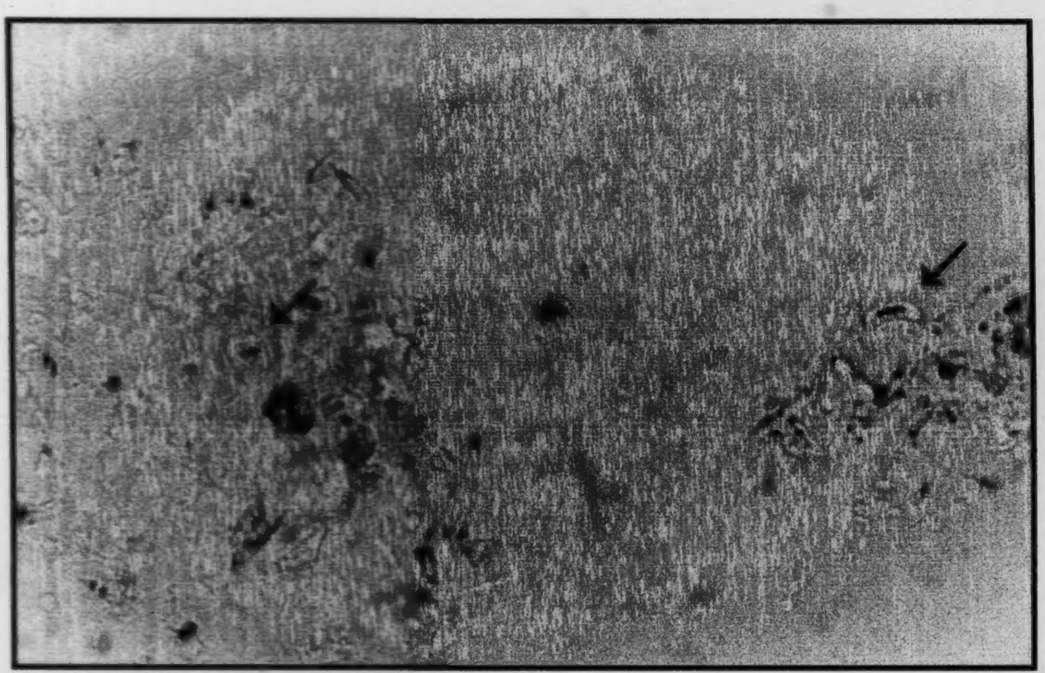


Plate 3.1. Saddles (*Bouteloua sp.*) (400X).

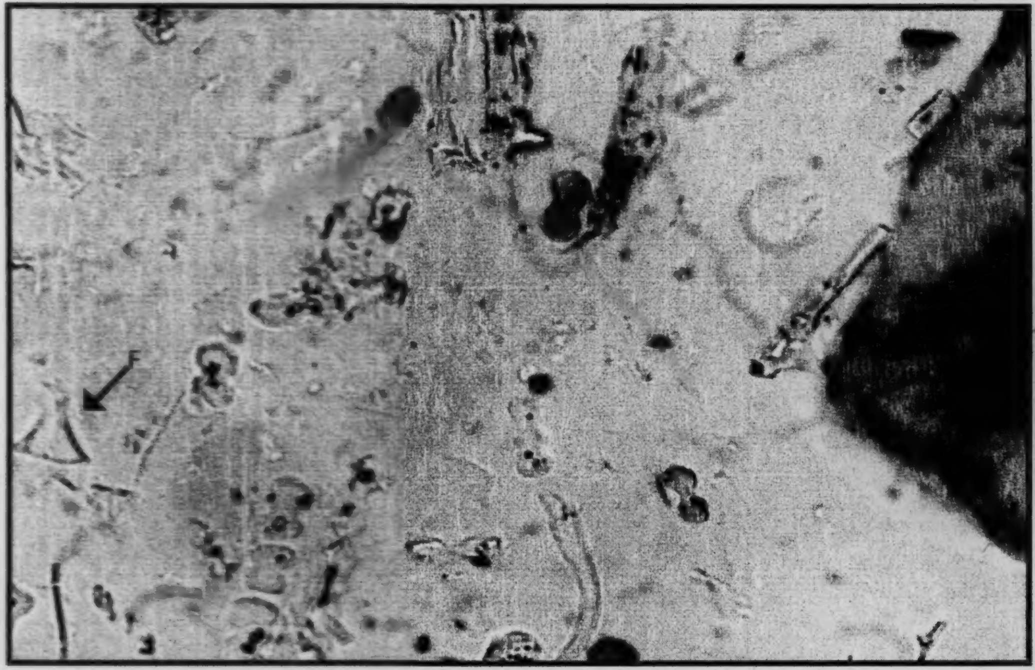


Plate 3.2. Bilobates and a (F)an shaped bulliform phytolith (*Oryzopsis sp.*) (400X).

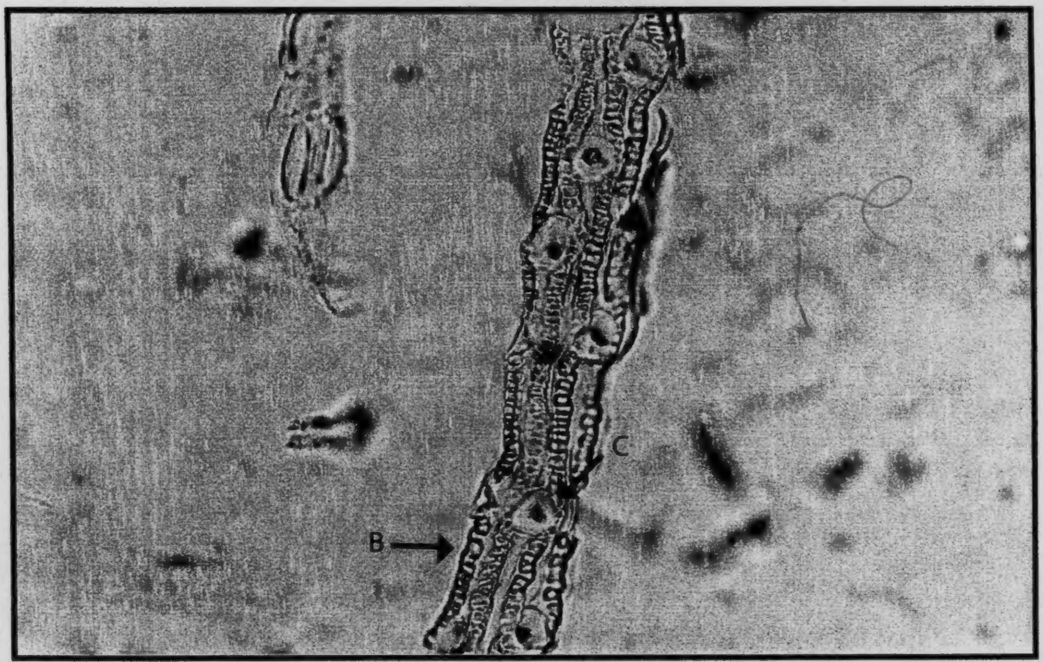


Plate 3.3. (B)ranching epidermis and (C)ircular short cell phytoliths (*Festuca sp.*) (400X).

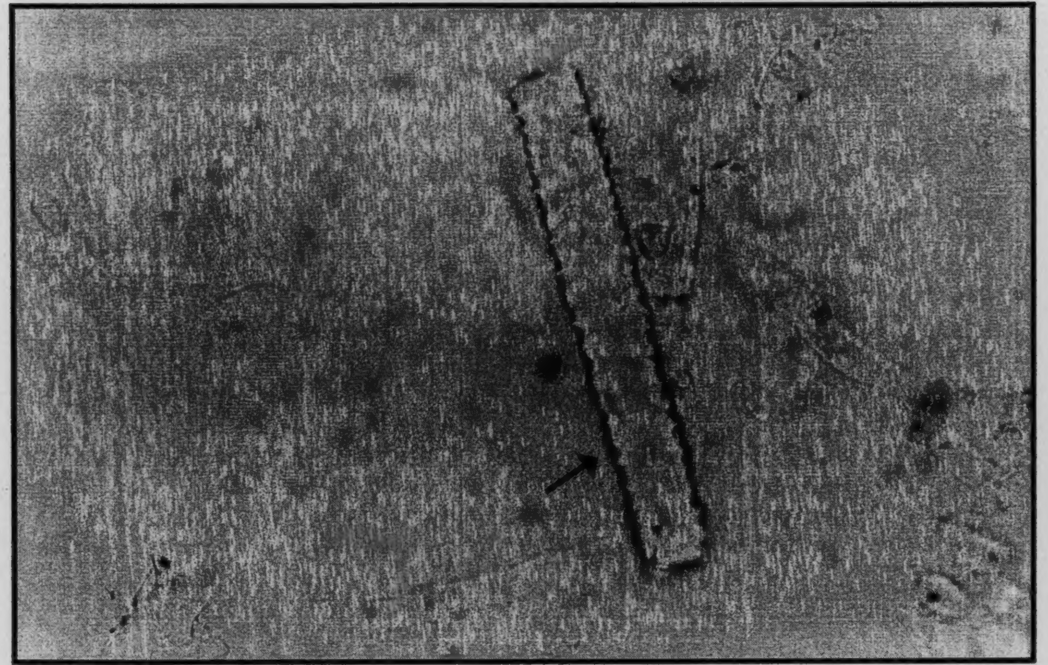


Plate 3.4. Epidermal quadrilateral (*Poa sp.*) (400X).

An early application of using discrete phytolith particles as both a paleoenvironmental indicator and a source of cultural information is provided by Lewis' (1978, 1981) analysis of samples from the Hudson-Meng archaeological site, a bison kill in Nebraska, associated with the 'Alberta Complex' and radiocarbon dated at 9,820 BP (Lewis 1978). She found a high percentage of festucoid (short grass) phytoliths. This was consistent with the presence of 'humid' type grasses likely due to the presence of a nearby spring (Lewis 1978). Samples from the Horner Site, Wyoming, dating to 9,000 BP were similar to those from Hudson-Meng (Lewis 1981). Lewis also used phytolith data to gain cultural information. Samples from a hearth and bone bed yielded a high percentage of chloridoid grass phytoliths likely due to the burning of dung in hearths and the viscera of butchered bison left in the bone bed. Analysis of coprolites demonstrated that the bison were feeding selectively on chloridoid grasses (Lewis 1978). Lewis (1981) was able to delineate different activity areas within the site by taking a trench sample (in the same stratigraphic level along a horizontal surface).

While the cultural information gained from this study is interesting, from a paleoenvironmental aspect, data from archaeological sites are fraught with methodological problems. It is poor practice to sample archaeological sites for paleoenvironmental purposes as there is bound to be a degree of distortion due to site activities. This is the so-called 'cultural filter' and can be accounted for by sampling both on and off the archaeological site.

3.2. The Nature of Phytoliths

3.2.1. Silica from Soil to Silica in Plants

Silica in solution is present in soil water almost entirely as monosilicic acid, $Si(OH)_4$. Silica in this form is mainly derived from the weathering of silicate minerals such as quartz and feldspar (Jones and Handreck 1967). The concentration of silica in soil water is partially determined by pH, passing into solution as monosilicic acid at a pH of 9 or lower, and as silicate ions at higher pH values (Jones and Handreck 1963; Mulholland and Rapp 1992a). Soils with pH 9 or lower are more likely to contain significant phytolith deposits.

Plants absorb silicic acid through their roots and transport it throughout the plant via the xylem (water conducting tissue). The amount of silica deposited in the plant is typically proportional to the availability of silica in soil and the plant's transpiration rate (Jones and Handreck 1967). The development of phytoliths is related to a number of additional factors including climate, the nature of the soil, soil moisture, plant maturity and the taxonomic identity of the plant.

Plants absorb silica differentially depending on the species. In general, Poaceae contain many times the concentration of silica compared to arboreal species grown under the same conditions (Jones and Handreck 1967). For example, Pinaceae phytolith content varies between 0.08% and 1.37% dry weight, while in grasses it is 1.0% to 7.7% (Klein and Geis 1978). This is thought to result from the greater transpiration rate of grasses and also possible differences in metabolic processes. For example, dicotyledons may actively exclude the uptake of monosilicic acid (Jones and Handreck 1967). It has long been noted that plants of a single species may contain different concentrations of silica when grown in different soils. This is a function of environmental factors regulating the amount of silica in solution available to plants.

3.2.2. From Silica in Plants to Phytoliths

Once absorbed into the plant, monosilicic acid is polymerized into a solid form of silica (amorphous silicon dioxide, SiO_2) when water is lost through transpiration. Silica deposition can occur in three locations. The first is in the cell wall through a process called membrane silicification. Cell walls that have accumulated cellulose and/or lignin are likely to be impregnated with silica. As a result, many plant tissues including xylem, epidermal and mesophyll cells are typically silicified. The second deposition process is the filling of the cell lumen (the space bounded by the cell wall).

The third occurs in the intercellular spaces of the cortex (Parry and Smithson 1958; Piperno 1988).

Investigations into the function of silica in plants have yielded few concrete results. While it is not an essential nutritional element, it seems to be of benefit to the plant. In the absence of silica, plants may be stunted or structurally weak (Kaufman *et al.* 1985). Silica in plants may serve the following purposes such as increased resistance to fungal and insect attack through the provision of a mechanical barrier to the breach of cell walls. It may aid in the metabolism of phosphorous, increase the capability to cope with heavy metal toxicity, increase translucence of photosynthetic structures, allow a greater resistance to herbivory and increase the efficiency of transpiration (Parry and Smithson 1958; Jones and Handreck 1967).

The timing of silicification in grasses has been studied in detail. Results suggest that silica deposition occurs throughout the developmental life of the plant and is species dependent (Piperno 1988). Generally, the more mature the plant, the greater the amount of silica deposition. For example, Parry and Smithson (1958) noted that it was not until plant maturity, when leaf expansion was complete, that 'excess' silica was deposited. Jones *et al.* (1963) demonstrated that after only a month and a half, the oat leaf blade was largely silicified while silicification of cellular tissue continued through the life of the plant.

It was realized early in phytolith studies that the distribution of phytolith concentrations is not uniform throughout an individual plant (Parry and Smithson 1958). For example, the glumes, palea, and lemma of various cereal crops show much higher concentration of silica bodies than other structures (Jones *et al.* 1963; Geis 1978). Another excellent example of this was found by Sangster and Parry (1969) in three grasses. Leaf bulliform cell silicification was most abundant in the leaf tip and this decreased towards the base of the leaf. These researchers postulated that leaf tip silicification would render the stomata cells inoperable which would as a result, reduce transpiration in the leaf leading to lower amounts of silica entering the leaf to be deposited at the base (Sangster and Parry 1969). In other words, there is a lower rate of transpiration due to leaf tip silicification which would decrease transpiration and subsequent silica deposition. Prior to phytolith formation, a degree of cellular maturation is required. It would seem that silica is deposited in an ordered sequence following leaf ontogeny and it is generally not until cell expansion was complete that silicification began (Sangster and Parry 1969). Non-uniform silica deposition is consistent with the notion that silica is carried through the transpiration system and is deposited in greatest quantities in regions where water is lost in the greatest quantities (Jones and Handreck 1967).

Just as not all plants produce phytoliths during the same developmental stages, not all parts of plants have the same concentration of phytoliths. It can also be said that not all species of plants even produce identifiable silica bodies. This results in certain 'blind spots' in the fossil phytolith record (Piperno 1988). The possibility of this differential production needs to be taken into account when interpreting phytolith data. Piperno (1988) has compiled a list of producers and non-producers in order to help deal with this problem. From this list, researchers can determine which species may be significantly underrepresented or not represented at all in the phytolith record (Piperno 1988). While listing phytolith producers, Piperno also comments that quantifying levels of production aids in interpreting species representation in the paleobotanical phytolith record. This allows for a paleobotanical picture of greater detail.

3.2.3. Phytoliths in Plants to Phytoliths in Soil

Phytoliths are deposited in soil by a number of methods. Commonly, deposition occurs when a plant dies and decays releasing its phytoliths into the organic layer of the soil profile. One must also consider the possibility of vertical and horizontal movement in the soil profile as well as phytolith taphonomy (the nature of deposition and preservation).

It was thought that deposition should be highly localized as phytoliths are formed in vegetative structures and are released at the surface and in shallow subsurface soils (Piperno 1988; Mulholland and Rapp 1992a). This may be overly simplistic. First, phytoliths can be transported into an area through many vectors. Even though they are not designed for dispersal, phytoliths may be distributed by fluvial, wind, wind-fire, and in herbivore feces (Fredlund and Tieszen 1994). This means that phytoliths can be a measure of extra-local (20 m to several hundred meters) or regional (more than several hundreds of meters) measure of vegetation as well. Phytoliths can move considerable distances as a component of wind-blown dust. For example, H.M.S. *Vidal* encountered a dust storm 500 km off the African coast which lasted "for more than 30 hours; during daylight the sun was completely obscured" (Folger *et al.* 1967: 1243). It was found that a large proportion of this dust was opal phytoliths from terrestrial sources. Also, remember that Darwin collected phytoliths from the sails of HMS *Beagle*.

Second, it is unlikely that phytolith deposition is a snapshot of standing vegetation. It is more likely to be a measure of average plant community composition over a period of soil formation. Fredlund and Tieszen (1994: 37) call this 'inheritance,' by which they mean the incorporation of phytoliths into the soil assemblage over a period of hundreds of years. This would leave the phytolith assemblage an admixture of deposition; in other words an average measure of longer-term community composition.

Studies in a number of areas and in a variety of soil types, show that there is an "overwhelming consistency of phytolith stability within the A horizons of the soil profiles and…to the top of the B horizon." (Beavers and Stephen 1958; Rovner 1986: 24). After an extensive literature review, Rovner (1986) concluded that phytoliths are no different from any other soil constituent with regard to the integrity of their distribution in the soil column. Their distribution is subject to the same variables of hydrology, wind and water erosion and the physical nature of soils. Phytolith illuviation (i.e., the downward movement through the soil profile as a result of water action) is however of little significance (Piperno 1984).

As mentioned previously, phytoliths are susceptible to chemical degradation at pH 9 or greater (Rovner 1983; Mulholland and Rapp 1992a). They are also subject to mechanical abrasion or breakage over time. Differences in density and thickness of phytolith walls, the presence of hollow cavities and general morphology all play a role in durability (Rovner 1983). Abrasion and chemical degradation generally increases over time. Even so, phytoliths have been recovered intact from Holocene deposits to those of considerable antiquity, as old as the Paleocene epoch (60 to 70 million years ago).

3.3. Phytolith Classification

Using biogenic silica as a paleoenvironmental/paleobotanical tool relies on the persistence of phytoliths with unique morphologies in soil (Klein and Geis 1978).

Rovner (1971: 343-344) wrote:

> "For any fossil system to be useful to the archaeologist at least three criteria must be met. The material must withstand decomposition, exhibit sufficient morphological differences to be of taxonomic significance, and provide sufficient quantities to reflect the nature of the entire assemblage from which it is derived."

Phytoliths are made primarily of inorganic opaline silica which is extremely resistant to decay. There are sufficient morphological differences between phytoliths both between and within plant groups. Resolution at varying levels of taxonomic specificity (e.g., family, subfamily, genus, and species) has been demonstrated. Individual phytoliths can denote a specific taxum (Piperno 1988).

Problems to be considered in phytolith classification are multiplicity and redundance (Rovner 1971). Multiplicity refers to the fact that one plant can produce several different types of phytolith. Additionally, many plants with different taxonomic affinities can produce some similar phytolith morphotypes, a phenomenon known as redundance of forms. These must be considered when interpreting phytolith data.

Phytoliths are usually found in statistically sufficient quantities to provide a representation of a fossil plant assemblage. As with pollen analysis, taxa provide differential representation in the phytolith record. As discussed above, some plants produce few to no phytoliths, some produce no diagnostic ones, while others are prolific producers (Mulholland and Rapp 1992a). This must be taken into account when interpreting data. However, strong correlations have been shown between modern plant communities and associated modern phytolith assemblages (Twiss *et al.* 1969; Blackman 1971; Fredlund and Tieszen 1994, 1997).

3.3.1. Phytolith Identification on the Columbia Plateau

There is no standard classification scheme for phytolith analysis. Classification of phytolith morpohology varies with the purpose of the investigation and the geographic region being examined. There are some general classificatory divisions and terminology common to all phytolith studies. Phytoliths can be characterized by size, two and three dimensional shape, surface ornamentation, thickness of cell wall, orientation of articulated phytoliths and their relation to surrounding silicified cells (Piperno 1988).

Initial research in phytolith morphology focused on the location of the morphotypes in modern plants. Phytolith classification for paleoenvironmental work must be based on morphology alone, because phytoliths recovered from soil samples occur as discrete grains, not articulated tissue fragments (Mulholland and Rapp 1992b). Based on phytolith morphology and location in modern plants, the location of paleo-phytoliths in their host plants can then be inferred.

For phytolith assemblage counts, the present study will use modified versions of counting schemes developed by Fredlund and Tieszen (1993) and Eccleston (1999). Eccleston (1999) collected over 100 plant species from the Columbia plateau, processed 171 samples and classified phytoliths from 80 species. She devised an effective classification scheme for this region and applied it to an archaeological site found on the Joseph Plains adjacent to the lower Salmon River Canyon (Fig. 2.3). Her study had the expressed purpose to "primarily…identify root crop phytoliths in…soil samples." (Eccleston 1999: 154). After a thorough study of her comparative material and that available at the University of Calgary this regional comparative methodology was adapted with the specific goal of using phytolith morphotypes that would help in paleoenvironmental reconstruction. In addition to Eccleston's work, this study will use a modified version of the Twiss *et al.* (1969) classification scheme for grass short-cell counts as will be discussed later in the Methods section and Appendix A. The modified 'Twiss *et al.*' approach to grass classification ignores other types of vegetation changes which may be potentially important (Fredlund 1993). For this reason diagnostic phytoliths of non-grasses identified by Eccleston (1999) and in earlier studies (e.g., Brydon *et al.* 1963; Mehra and Sharma 1965; Rovner 1971; Klein and Geis 1978; Bozarth 1992) will be used to document fluctuations in plants with woody tissue.

3.3.2. Non-Grass Phytolith Morphology and Classification

Phytolith studies are still focused mostly on classification matters and on documenting variation found within and between geographic regions. Even so, in the past fifteen years, the use of phytoliths has become ever more effective in paleoenvironmental interpretation. Phytoliths are becoming an indispensable tool with growing evidence of their validity as a paleoenvironmental proxy.

The morphology of phytoliths is determined by the type of cell accumulating silica and its location in the plant body (Piperno 1988). The degree of silicification can be categorized as follows: a) complete or near complete filling of cells forming casts; b) a fragile and thin silicification of cell linings resulting in angular or plate-like silica deposits; c) complete cell replacement; d) silicification of plant hairs, hooks, trichomes, or spines; and e) miscellaneous adventitious particles not conforming with organic structures.

As discussed above, phytolith formation, morphology, and hence classification, is rather complex. The silicification of different plant tissues generates numerous phytolith shapes in a single species (multiplicity). This, in combination with interspecific redundance of shapes and structures, complicates the classification and interpretation of phytoliths in soils.

Verma and Rust (1969) and Wilding and Drees (1968, 1971) were among the first North American researchers to study phytoliths in deciduous angiosperms.

Biogenic opal was derived predominantly from leaf tissue (Geis 1973). Morphological variation was minimal in silica particles from mesophyll, stomata, vascular elements, chrystalloids and parenchyma (Geis 1973). Siliceous epidermal hairs and hair cell bases exhibit sufficient differences to allow for taxonomic identification. The following is a summary of major classes of non-grass phytolith morphotypes.

1) Epidermal phytoliths are formed in the outermost cell-layer of the plant body. They are classified into two broad categories: anticlinal (Plate 3.5), which are sinnuate or have wavy margins and polyhedral (Plate 3.6), which have four to eight sides and are generally blocky in overall shape (Piperno 1988).

Anticlinal epidermal phytoliths are produced in many deciduous tree leaves, wood dicots and members of Fabaceae. They are not found in monocots (Bozarth 1992). Polyhedral epidermal phytoliths have been identified in the leaves of many deciduous angiosperms, herbaceous dicots, and conifers and in the monocot families Commelinaceae and Poaceae (Piperno 1988; Bozarth 1992).

Epidermal phytoliths are similar in overall size and shape in grasses, angiosperms and gymnosperms (Klein and Geis 1978). Consequently they are of little use in classification schemes.

2) Phytoliths are also found in hair cells of leaf epidermis. Silicified hair cell phytoliths are often triangular with differently shaped bases. They can be either segmented (Plate 3.7), arising from multi-celled hairs, or non-segmented (Plate 3.8), arising from unicellular hairs. Hair cell phytoliths are the most common type found in dicots (Piperno 1988). Different surface decoration and structure can suggest taxonomic affiliation. For example, non-segmented hair cells with surficial spines have been observed in only four families: Borgainaceae, Utricaceae, Moraceae and Ulmaceae (Piperno 1988). Hair cells are typically not diagnostic as they are found in dicotyledonous plants and also in monocots such as grasses and sedges (Piperno 1988).

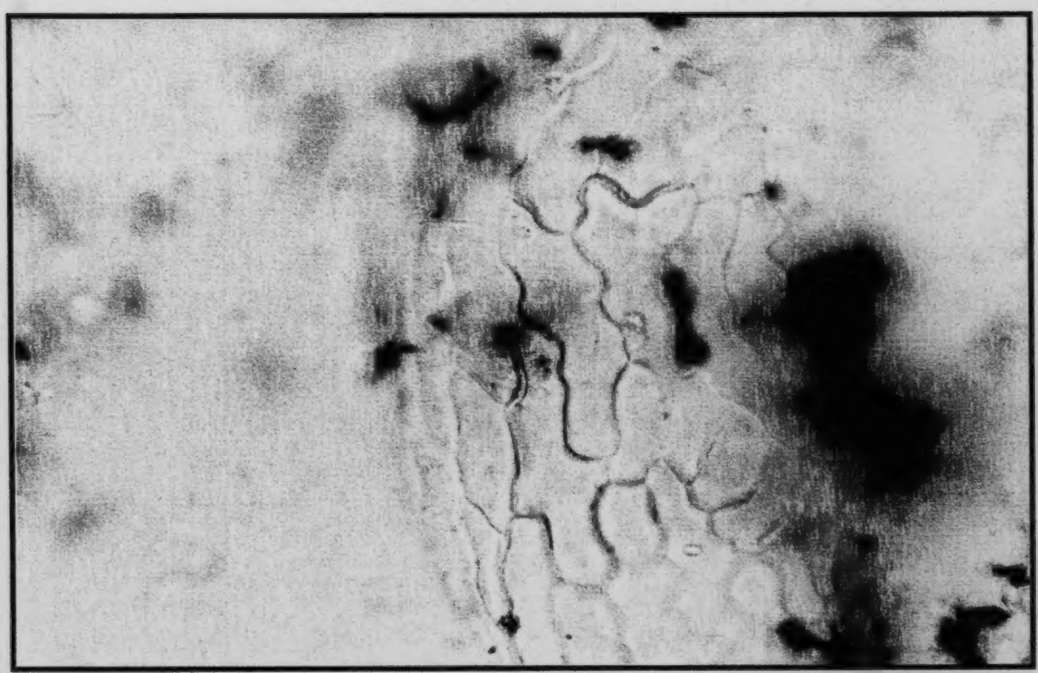


Plate 3.5. Anticlinal epidermis (*Artemisia sp.*) (400X).

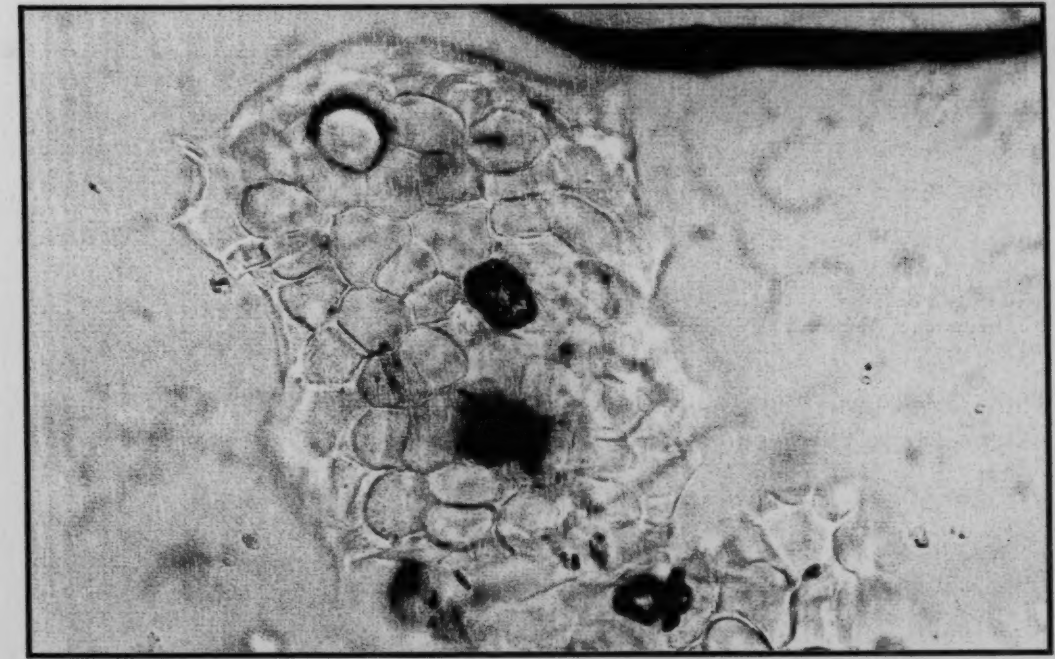


Plate 3.6. Polyhedral epidermis (*Balsamohriza sp.*) (400X).

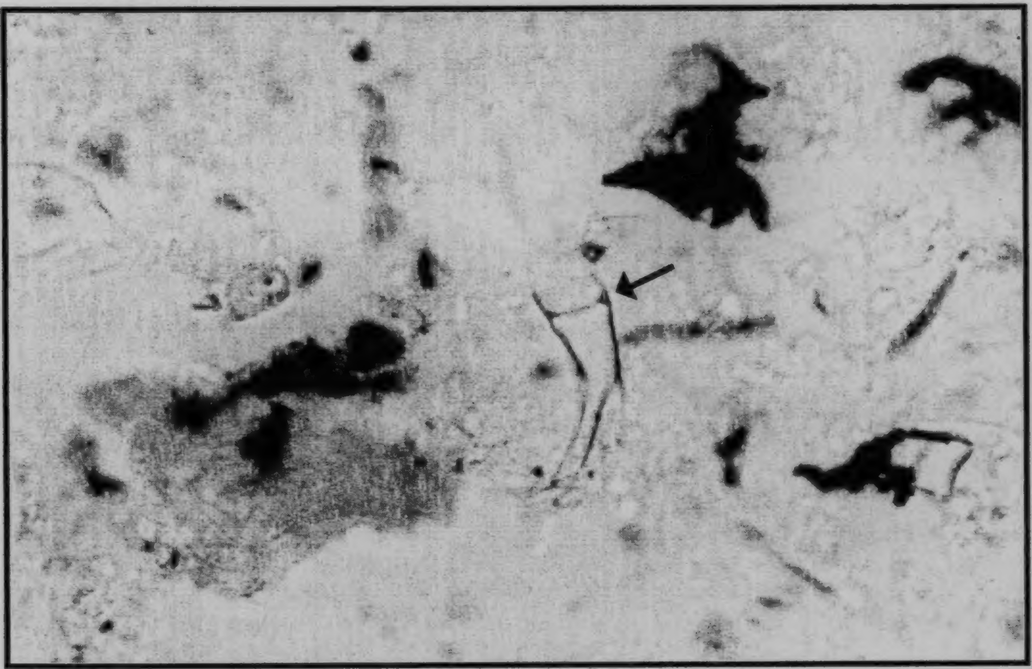


Plate 3.7. Segmented hair cell (*Balsamorhiza sp.*) (400X).

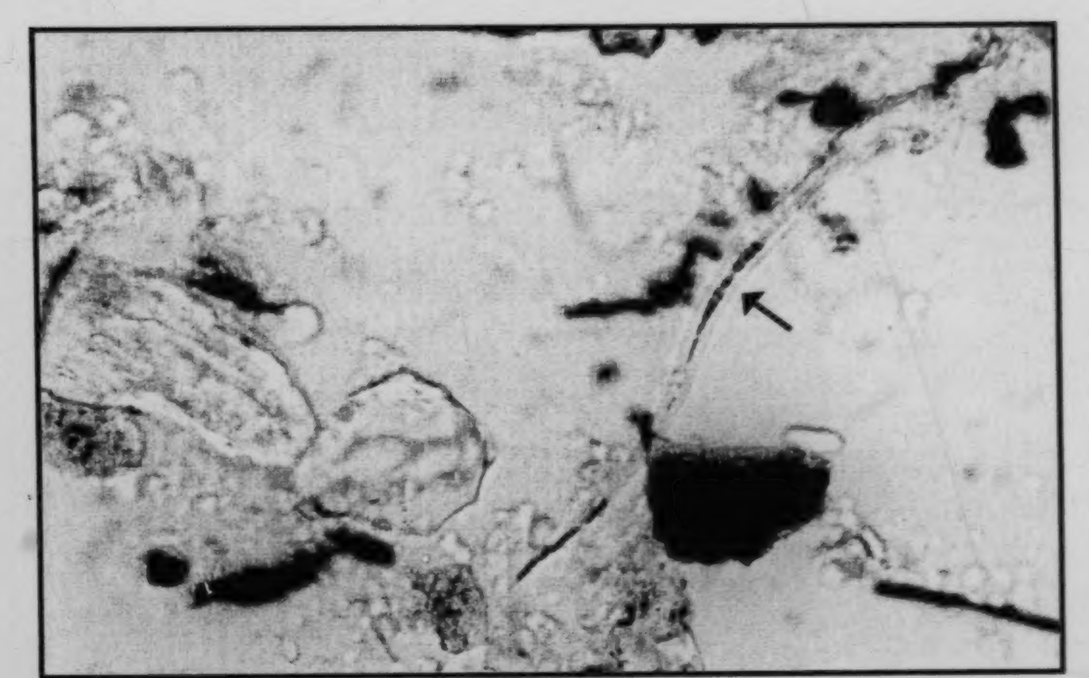


Plate 3.8. Non-segmented hair cell (*Lomatium sp.*) (400X).

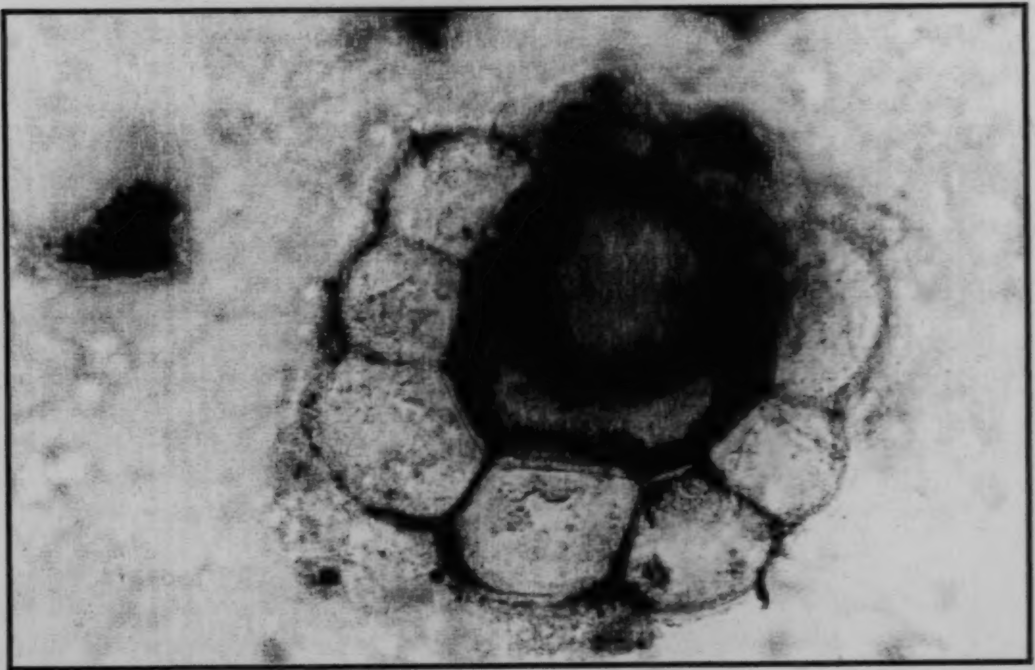


Plate 3.9. Hair cell base (*Helianthus sp.*) (400X).

Hair cells are rooted in hair base cells. Hair base cell phytoliths are spherical with a circular mark in the center (Piperno 1988). They are common in dicotyledons and are not observed in monocots. Some hair cell phytoliths are diagnostic. For example, they have been recognized for *Helianthus* sp. (Plate 3.9), *Rosa* sp., and Ulmaceae (Plates 3.10) (Eccleston 1999). Geis (1973) noted unique hair base cell phytoliths for *Celtis* sp. (Plate 3.11). In other cases, phytoliths produced in this structure are not as diagnostic. For example, 'armed' hair base phytoliths occur in five families: Compositae, Cucurbitaceae, Moraceae, Boraginaceae and Ulmaceae (Piperno 1988).

3) Stomata and guard cells are often silicified and found as phytoliths (Plate 3.12). These vary little morphologically and hence are of little use in classification of discrete particles.

4) The ground tissue of the leaf, situated between the layers of epidermal cells and other specialized cells, is called mesophyll. Mesophyll typically is composed of photosynthetic tissues of the plant. There are two types of mesophyll: palisade mesophyll, with elongate cells at right angles to the epidermis, and spongy mesophyll which has a less regular appearance. Specialized cells, called stegmata, exhibit some diagnostic phytolith shapes such as has been observed in *Rosa woodsii* (Eccleston 1999).

5) Sclerenchyma cells add strength to mature plant structures, which is often in part due to the fact that they are silicified. Phytoliths derived from these cells are often similar between non-related taxa. However their presence or absence can help to distinguish between arboreal or herbaceous taxa (Piperno 1988).

6) Vascular plant tissue (phloem and xylem), that tissue which conducts food and water throughout the plant and helps support the plant, often becomes silicified. Tracheids are silicified parts of xylem tissue and appear as elongate and solidly

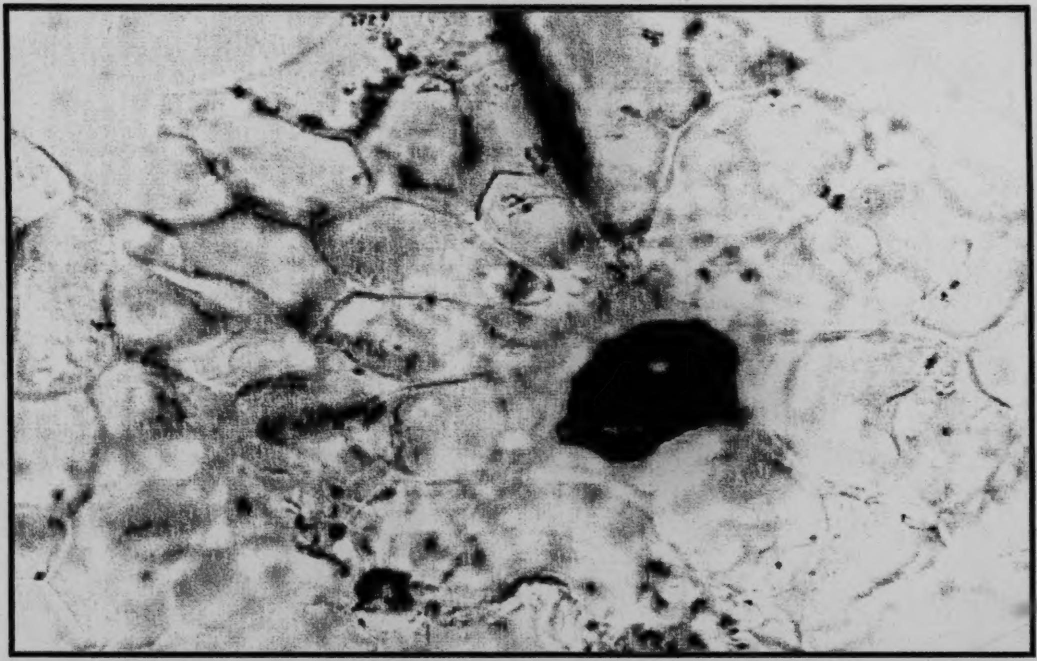


Plate 3.10. Hair cell base (*Ulmus sp.*) (400X).

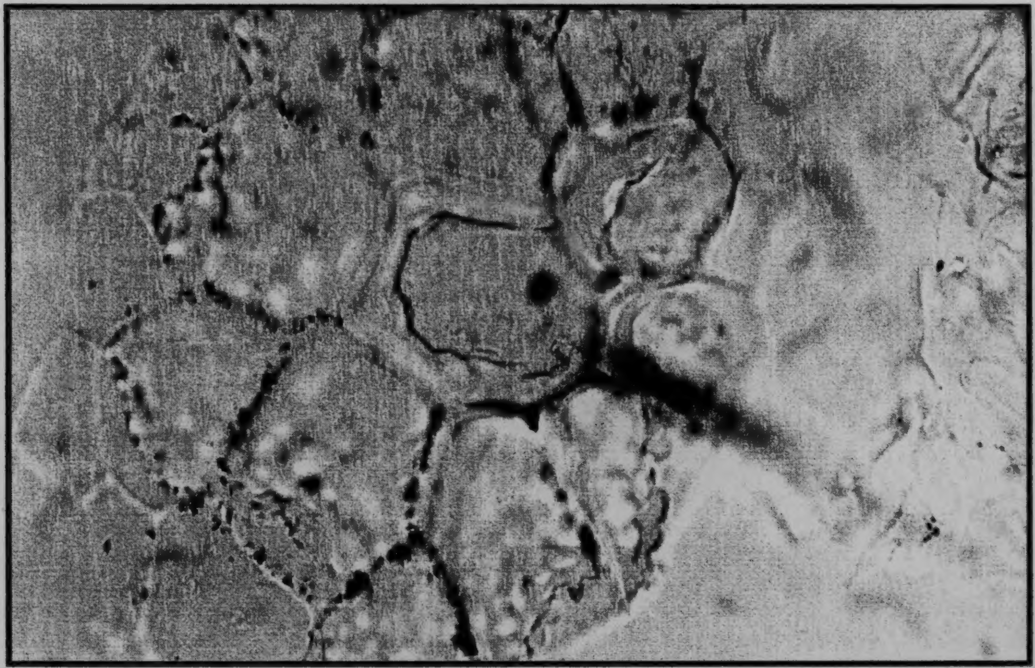


Plate 3.11. Hair cell base (*Celtis sp.*) (400X).

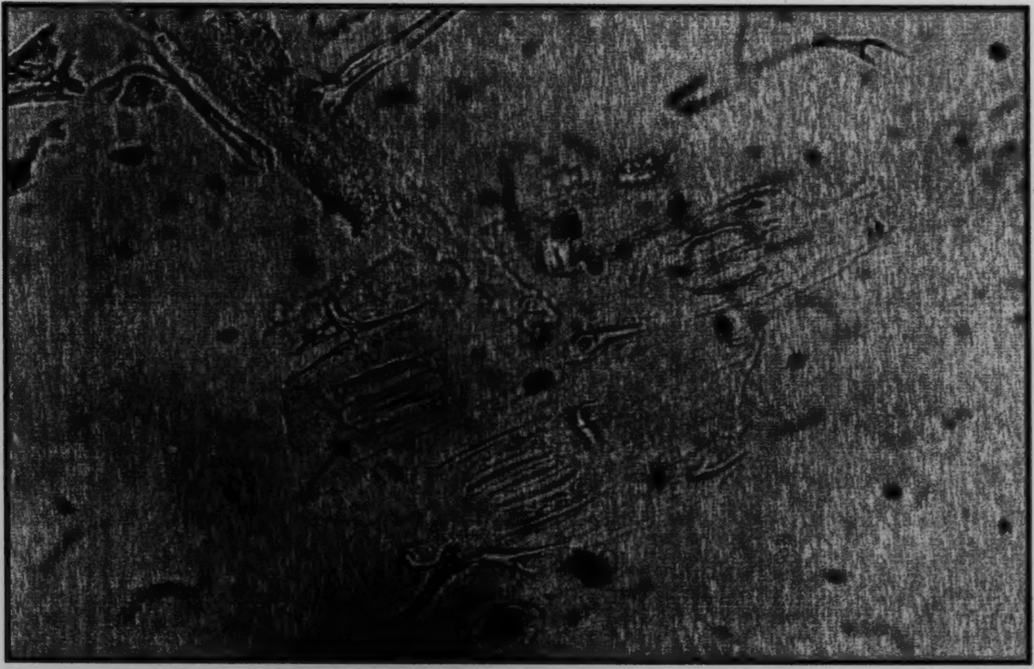


Plate 3.12. Stomata and Guard Cell Phytoliths (*Andropyron sp.*) (400X).

silicified bodies. Tracheary phytoliths have been found in vascular tissue of leaves of certain deciduous angiosperms and herbaceous dicots (Geis 1978; Bozarth 1992). They have no further value in plant identification as they all are morphologically similar.

7) Other phytolith morphotypes:

Cyperaceae produce phytoliths which are genus specific. They produce cone shaped or hat shaped phytoliths with smooth surfaces and uni- or multi-pointed apices (Plates 3.13, 3.14). All species of Cyperaceae produce large numbers of these distinctive phytoliths (Ollendorf 1992). The best evidence for the ubiquity of these comes from a study conducted by Mehra and Sharma (1965) in which siliceous bodies from 60 species in 13 genera of Cyperaceae were studied. While this is not the first study of silica formations in Cyperaceae, their study is the most comprehensive to date. They said of these phytoliths that "their structure is so distinctive and so precise that [they] designate[d] them the 'Cyperaceous type.'" (Mehra and Sharma 1965: 57). This was a pivotal study as the authors developed important criteria used to distinguish Cyperaceae from Poaceae in the paleobotanical record. Elongate and square/rectangular plate-like phytoliths and double outline trichomes (Plate 3.15) have all been found in both Cyperaceae and grasses (Twiss *et al.* 1969, class 4)

Spherical and aspherical phytoliths are produced in a limited number of Commelinoid families: Palmae, Marantaceae, Bromeliaceae, Cannaceae and Heliconicaeae (Piperno 1988). The surface decoration of these phytoliths allows for more specific classification. Palmae and Bromeliaceae have a spinulose (spiny) texture while Cannaceae, Marantaceae and Heliconiaceae are rugulose (bumpy). Spherical phytoliths are also found in Cannaceae and Heliconiaceae.

Eccleston (1999) identified deep profile bilobates, decorated bilobates and a 'cooling tower' morphotype which were diagnostic for *Allium* and *Camassia* (camas root) bulbs (i.e., Alliaceae and Agavaceae) (APG 1998). These forms were also observed by this author (Plates 3.16, 3.17, 3.18 and 3.19).

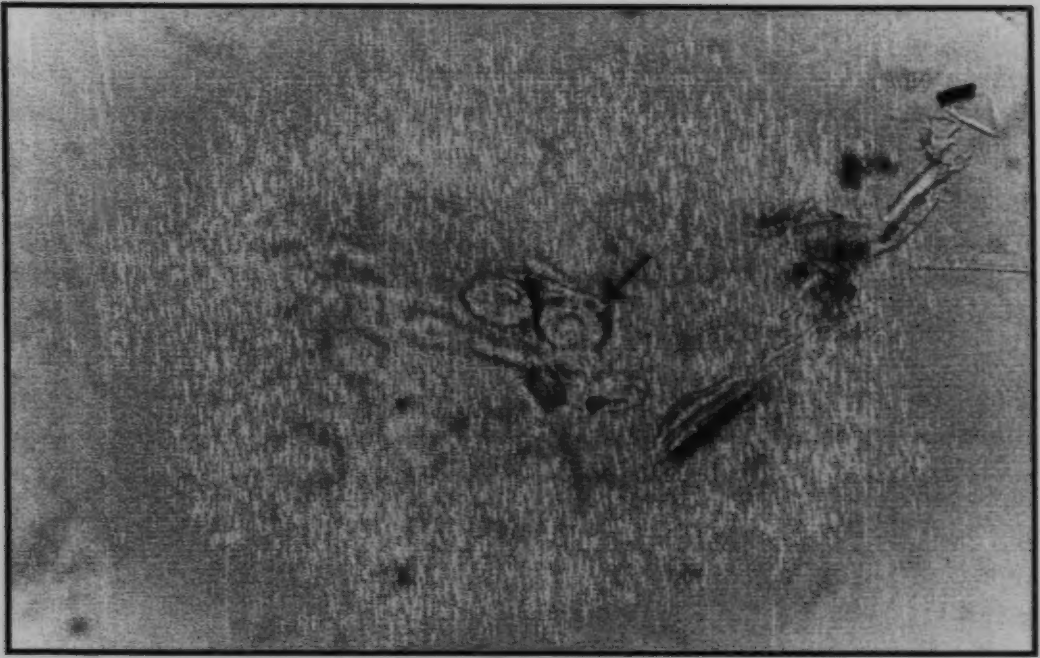


Plate 3.13. 'Hat shaped' Cyperaceous type (*Carex sp.*) (400X).

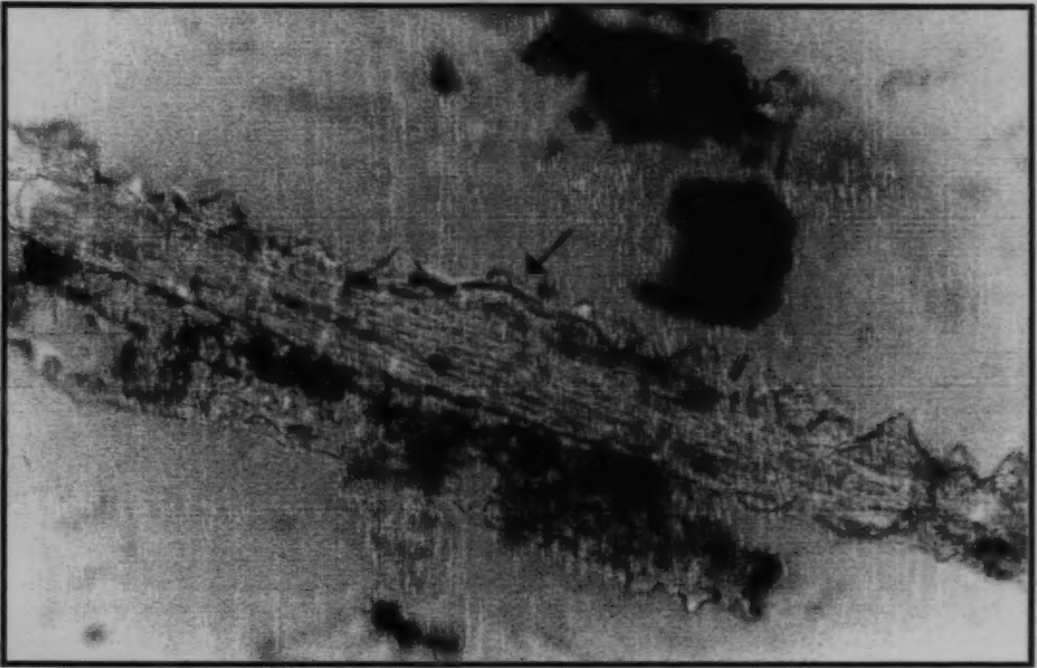


Plate 3.14. 'Hat shaped' Cyperaceous type (*Carex sp.*) (400X).

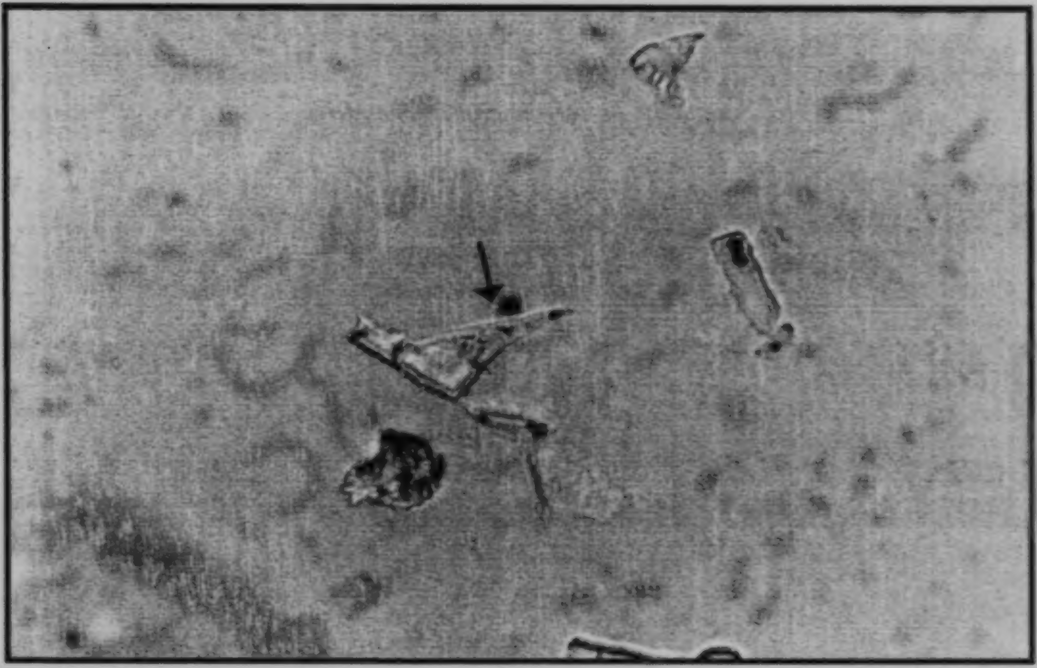


Plate 3.15. Double outline trichome (*Poa sp.*) (400X).

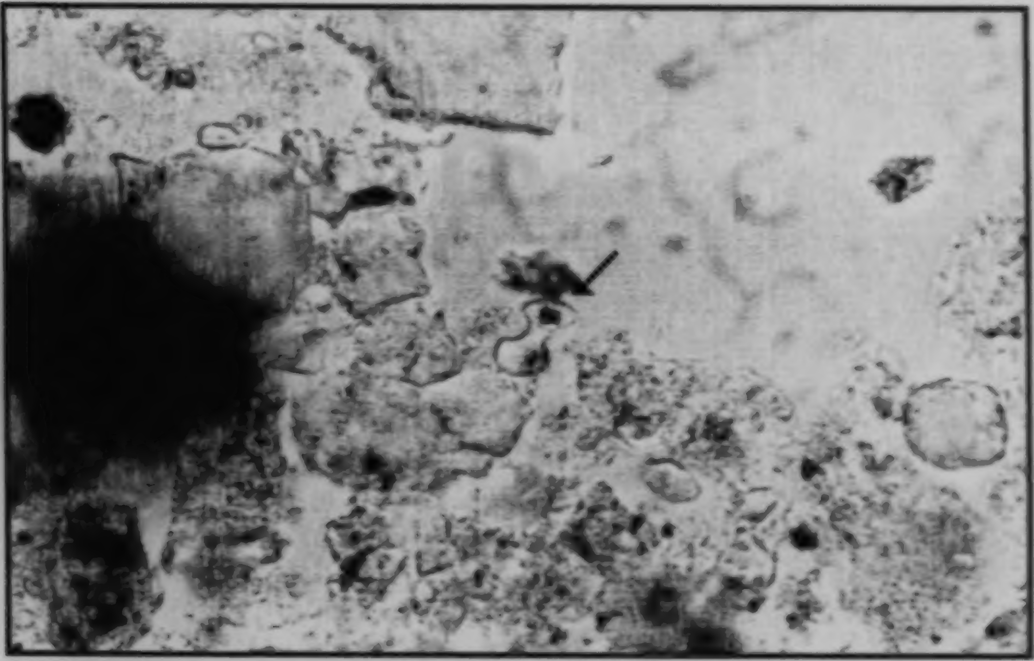


Plate 3.16. Plain bilobate (*Camassia sp.*) (400X).

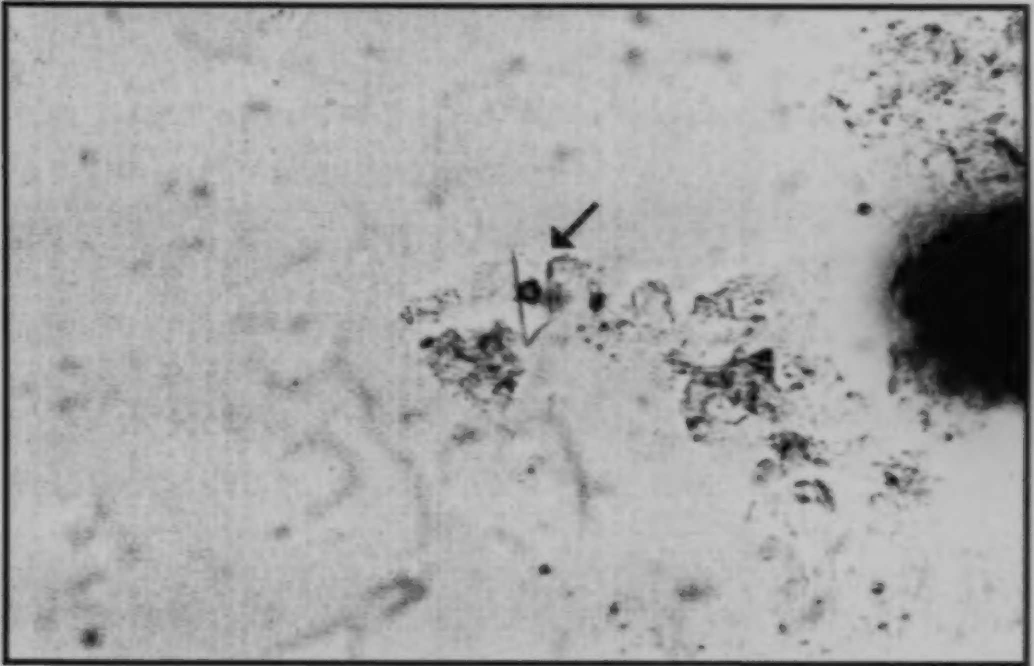


Plate 3.17. Bilobate (*Camassia sp.*) (400X) note three dimensional structure, this is a 'side view'.

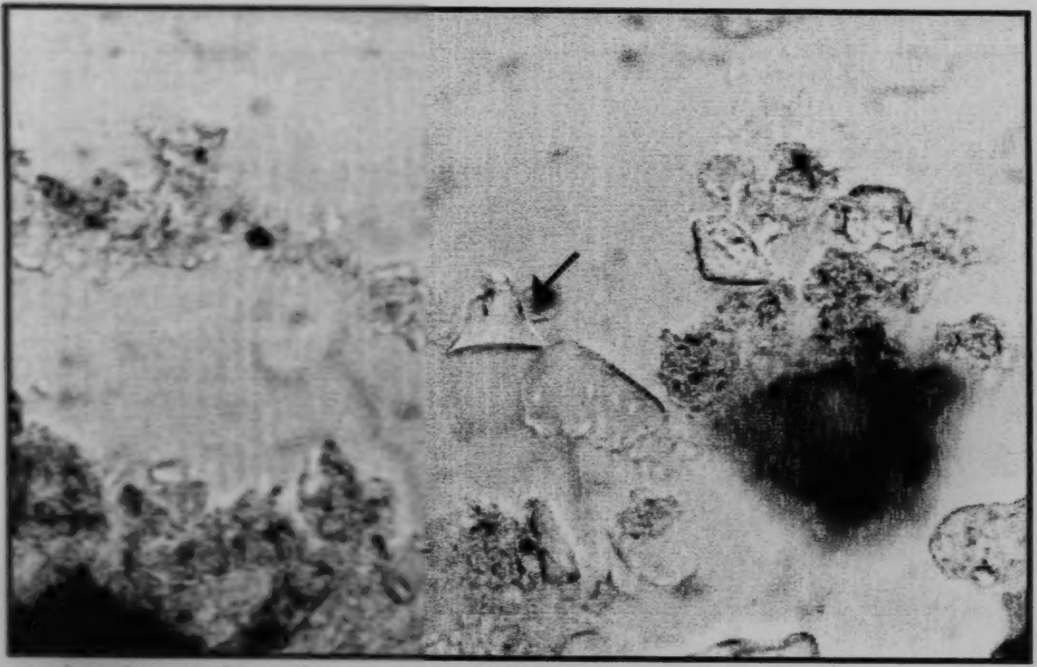


Plate 3.18. 'Cooling Tower' (*Camassia sp.*) (400X).

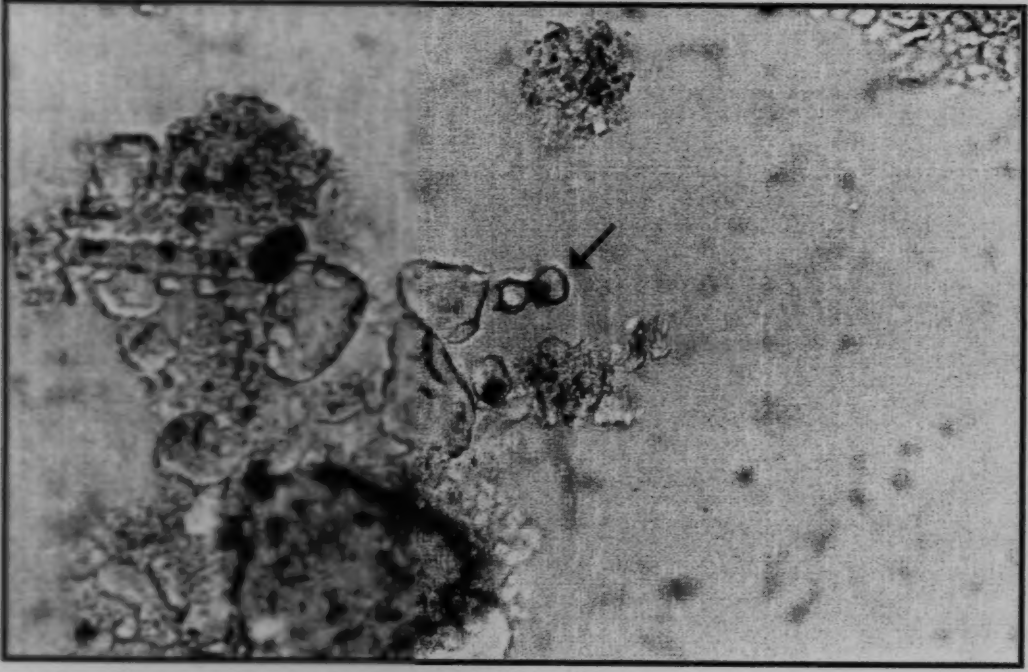


Plate 3.19. Decorated bilobate (*Camassia sp.*) (400X).

Numerous echinate (spiny) platelets are produced in fruits of *Celtis occidentalis* and *C. reticulata*. Vercuate (bumpy) and cystolith-like (large, spherical bodies with various distinctive surface features) phytoliths have also been identified in *C. occidentalis, C. reticulata* and *Ulmus americana* (Bozarth 1992; Eccleston 1999).

Klein and Geis (1978), and Eccleston (1999), isolated silicified endodermal cells produced in some species of Pinaceae. Distinctive endodermal polyhedral phytoliths were produced by *Picea*. *Pinus* and *Picea* both produced distinct epidermal phytoliths (smooth and pitted, blocky epidermal polyhedrons) (Plates 3.20, 3.21). *Picea* was found to have a diagnostic blocky, grainy form as well.

Brydon *et al.* (1963) first reported an 'antler type' of phytolith in *Pseudotsuga menziesii* found in soils in British Columbia. When checked against other species and known phytolith assemblages, it appeared to show no redundance. These particles, called asterosclerids, allow for classification at the genus level. This was later supported by the work conducted on Pinaceae by Klein and Geis (1978) and Eccleston (1999).

Larix sp. also produces several forms of phytolith many of which are diagnostic for the genus (e.g., "square netting-like fragments") (Rovner 1971). Unfortunately, it is thought that these forms are too fragile to be preserved which limits their usefulness in identification.

3.3.3. The Grass Phytolith Classification Scheme

Grass phytoliths have been studied in the greatest detail and may be classified with confidence at the subfamily level allowing for the identification of compositional shifts in grass dominated vegetation communities (Twiss *et al.* 1969; Rovner 1971; Blackman 1971; Geis 1978; Brown 1984; Piperno 1988; Mulholland 1986, 1989; Mulholland and Rapp 1992b; Fredlund 1993; Fredlund and Tieszen 1994, 1997; Fredlund *et al.* 1998). Grass short cell phytolith analysis is a feasible approach for the reconstruction of long term grassland community dynamics (Fredlund and Tieszen 1994). The studies referenced above have validated morphotype-grass subfamily

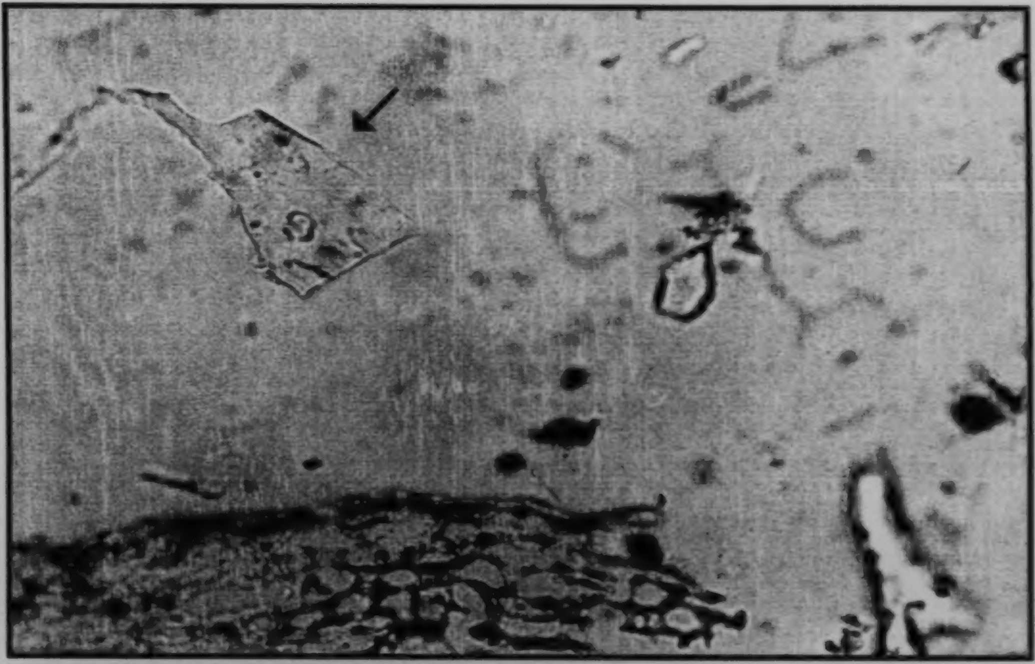


Plate 3.20. Blocky smooth epidermal polyhedron (*Picea sp.*) (400X).

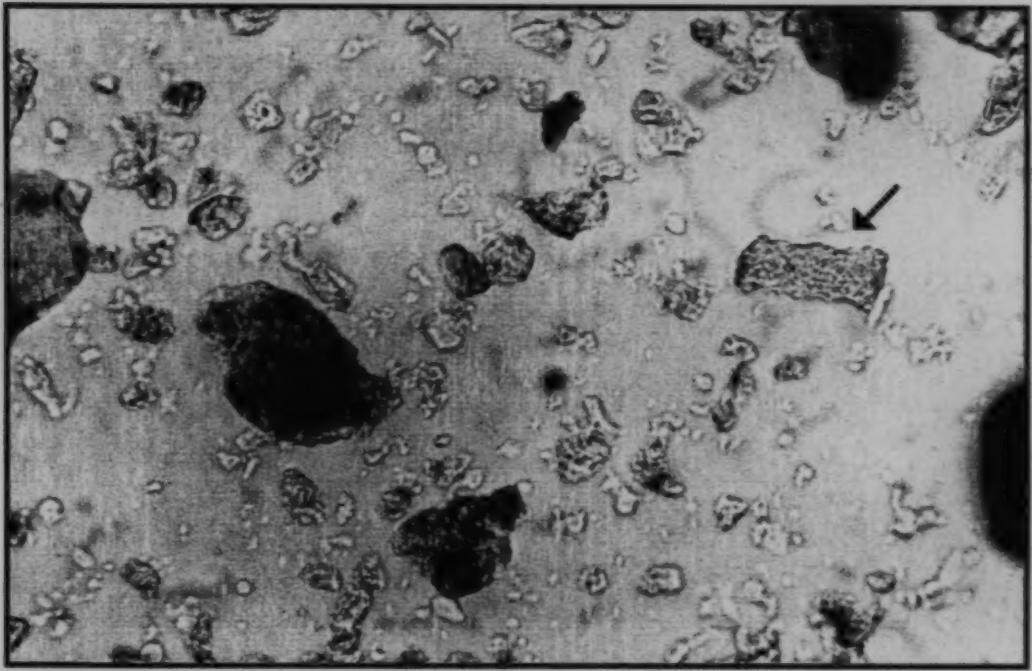


Plate 3.21. Blocky grainy epidermal polyhedron (Slide 01-18) (400X).

relationships, created a common vernacular, and have identified and begun to resolve specific taxonomic issues.

One of the most influential studies of grass phytoliths was conducted by Twiss *et al.* (1969). Along with being a landmark for the use of phytoliths as paleoenvironmental indicators, this study also devised a phytolith classification system that is still largely in use today (though with a few adjustments the body of comparative data grows) (Figure 3.1). Their classification system correlated the four major short-cell phytolith types found in grass leaves (bilobates, crosses, saddles, circular/acircular shapes) with the three subfamilies (panicoid, chloridoid, and festucoid) (Table 3.1). Changes have had to be made to the original 'Twiss *et al.*' phytolith short cell classification system in order to accommodate the rearrangement of grass taxonomy since their time. There are now twelve, not three, grass subfamilies (GPWG 2001). Of the Poaceae subfamilies, three are important on the Columbia Plateau: Pooideae (incl. Festucoideae), Panicoideae and Chloridoideae (incl. Eragrostoideae).

Grass epidermis gives rise to a number of different phytolith forms. Bilobates (formerly called 'dumbbells') and cross-shaped phytoliths occur in the Panicoideae or tall grass subfamily and in some bamboos. Saddle-shaped phytoliths occur in Chloridoideae, a subfamily which includes chloridoid, or short grasses, and also in many bamboos. In this subfamily, bilobates are uncommon and cross-shaped phytoliths are not produced (Piperno 1988). Circular and acicular phytoliths form mainly in Pooideae grasses and in a small number of other subfamilies.

Table 3.1. Summary of phytolith morphotypes for grasses.

Subfamily	Pooideae	Panicoideae	Chloridoideae
Photosynthetic Mechanism	C_3	Primarily C_4	C_4
Common Phytolith Morphotypes	Rondels Circular/elliptical Pyramidal Crenate Elongate *Stipa*-type	Lobate Polylobate Cross Elongate	Saddle forms Elongate

The shapes of discrete grass short-cell phytoliths can be used to identify subfamilies in which either C_3 or C_4 plants predominate. The designations C_3 and C_4 refer to the photosynthetic pathways by which plants fix CO_2 and convert it to sugars. During photosynthesis, plants discriminate against heavier carbon isotopes. C_3 plants discriminate against ^{13}C more strongly than do C_4 plants. Due to these differences in $^{12}C/^{13}C$ fractionation, C_4 plants tend to have higher $\delta^{13}C$ values and this can be detected in the soil (Cerling 1984, 1992; Amundson *et al.* 1988). The distribution of C_3 and C_4 grasses is sharply influenced by environmental factors making this a useful discrimination (Rovner 1983). C_3 and C_4 plants can coexist if there is a warm, wet spring with conditions favouring C_3 plants and hotter, drier conditions favouring C_4 plants in later months.

C_4 plants use water more efficiently and are typically found in arid or semi-arid areas where the mean monthly temperature of at least one-month is over 22°C (Twiss 1992; Clark *et al.* 2001). They produce 4-carbon compounds as the first stable product of photosynthesis (Rovner 1983). The C_4 pathway is common in Panicoideae (e.g., *Andropogon*, *Panicum* and *Sorghastrum*) and Chloridoideae (e.g., *Bouteloua* and *Buchloe*) (Jacobs 1987; Fredlund and Tieszen 1994). Twiss (1992) demonstrated that as one progresses north in latitude the abundance of C_4 plant decreases with July minimum temperature, mean annual degree days and length of freeze period.

On the other hand, C_3 plants predominate in areas of lower temperatures, greater moisture, higher elevations and are found mostly north of 45°N latitude (Twiss

1992; Clark *et al.* 2001). They produce 3-carbon phosphoglyceric acid as the first stable product of photosynthesis (Rovner 1983). Examples of C_3 species are abundant in subfamily Pooideae (e.g., *Poa*, *Festuca*, and *Agropyron*).

Along with differences in short-cell phytolith production between C_3 and C_4 grasses, there are also differences in epidermal cell phytolith production. C_4 grasses produce more silica overall, about twice the frequency of bulliform cells and two and a half times as many long epidermal cells. C_4 grasses produce no trichomes where C_3 grasses do (Kaufman *et al.* 1985). Eccleston (1999) found double outline trichomes to be indicative of Cyperaceae and Poaceae alone (Plate 3.15).

1) **Pooideae** (incl. Festucoid e.g., *Poa*, *Festuca* and *Agropyron*) are C_3 grasses. This is one of the largest subfamilies of Poaceae and predominates in grass flora of temperate zones in both hemispheres and high altitudes (MacFarlane 1987). There are several diagnostic short-cell phytolith associated with this subfamily.

Rondels are roughly circular to oval in abaxial/adaxial outline. They have a distinctly asymmetrical cross-section (Plates 3.22, 3.23) (Fredlund and Tieszen 1994). While these are produced in abundance in Pooideae, Mulholland (1989) and Mulholland and Rapp (1992b) noted that this morphotype was found only negligibly in other grass subfamilies.

Acircular and elliptical phytoliths, also called Keeled, are spheroid in overall shape but have a crested top (Plate 3.3, 3.22). This morphotype is diagnostic for Pooideae and is produced in especially large numbers in *Agropyron smithii* (Fredlund and Tieszen 1994).

Pyramidal phytoliths are common to C_3 grasses. The adaxial/abaxial outline is rectangular, and the cross-section trapezoidal.

Crenate forms are common in Pooid Grasses. They have sinuous or crenate abaxial/adaxial edges and a trapezoidal or asymmetrical cross-section (Plate 3.24, 3.25).

Stipa-type is a lobate phytolith common to the *Stipa* genus of C_3 grasses (Plate 3.26). Lobate morphotypes are common to Panicoideae (C_4 grasses) as will be

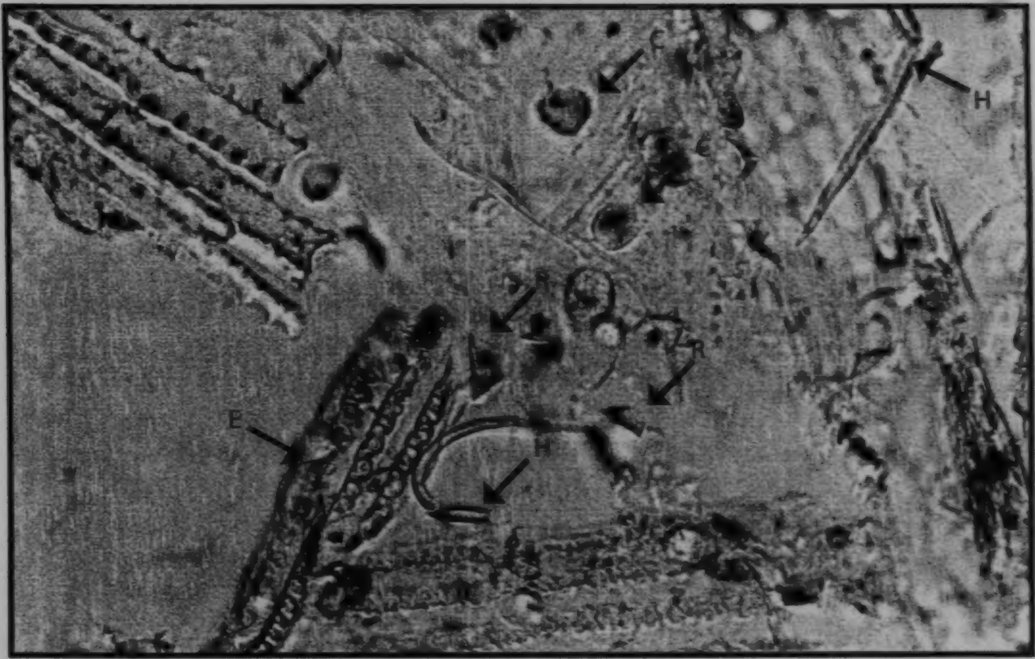


Plate 3.22. Various phytoliths (*Festuca sp.*) (400X)
(R)ondel, epidermal quadrilaterial with (U)pward projections,
(C)ircular, non segmented (H)air cell, (E)pidermal quadrilateral
with thin projection.

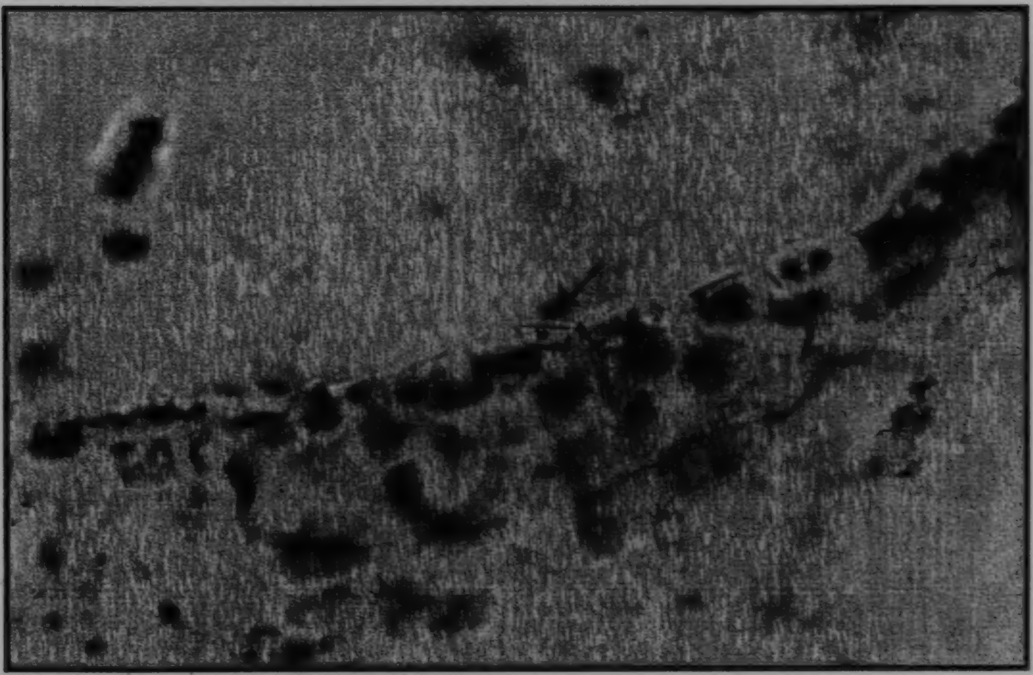


Plate 3.23. Rondels (*Puccinella sp.*) (400X).

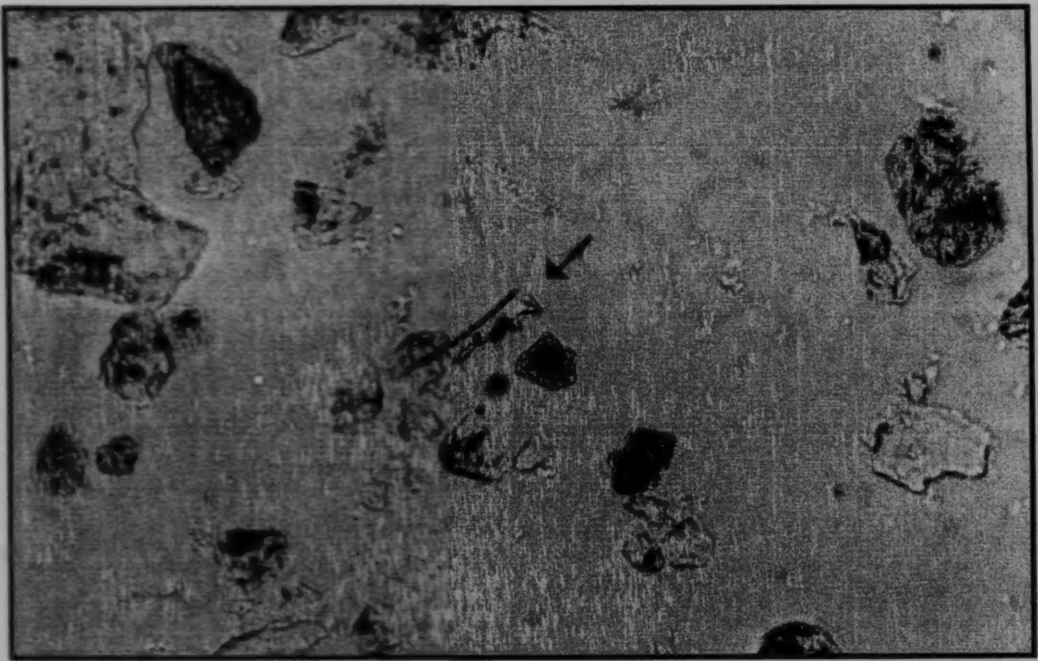


Plate 3.24. Side view of crenate (Slide 01-24) (400X).

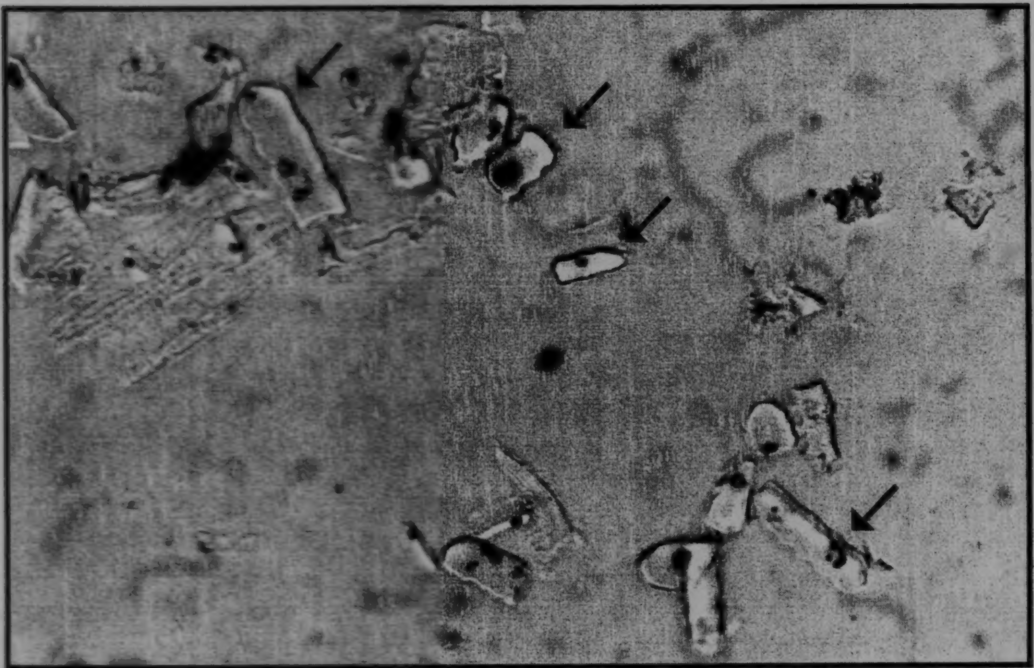


Plate 3.25. Crenates (*Poa sp.*) (400X).

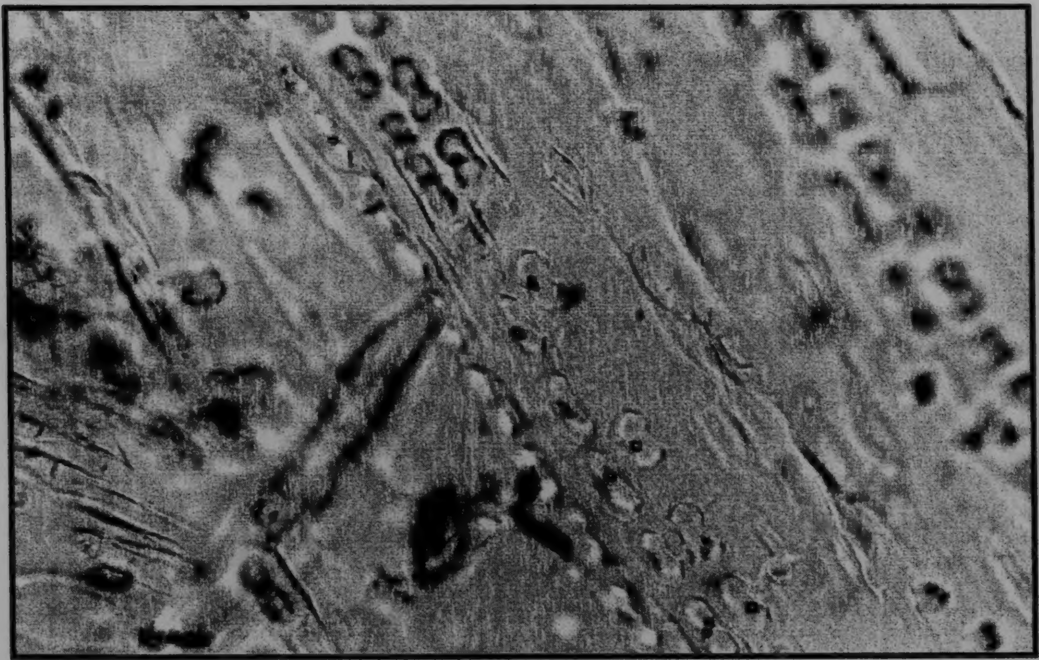


Plate 3.26. *Stipa*-type (*Stipa sp.*) (400X).

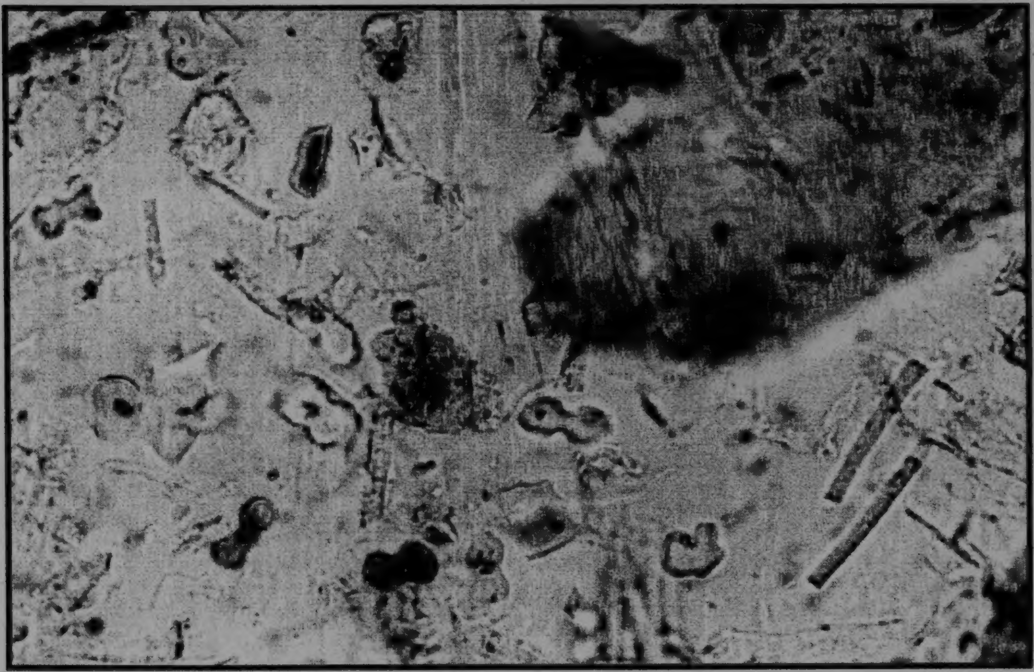


Plate 3.27. Lobate (*Oryzopsis sp.*) (400X).

discussed below. At first this phytolith type was thought to distort the pooid/panicoid subfamily determination as the lobate morphotype is not typical of the Pooideae subfamily (Blackman 1971). This was a problem until a morphological difference was observed between *Stipa*-type and normal C_4 lobate forms. The two can be distinguished in cross-section. *Stipa*-types taper towards the top whereas regular C_4 lobates do not (Mulholland and Rapp 1992b; Fredlund and Tieszen 1994).

2) **Panicoideae** (e.g., *Andropogon* and *Panicum*) subfamily is composed primarily of C_4 grasses with a number of specific phytolith morphotypes.

Simple lobate and polylobate morphotypes are two or more flat, disc-like lobes connected by a shank-like middle section (Plates 3.2, 3.27). They have a well developed lateral plane of symmetry (Fredlund and Tieszen 1994). All panicoids produce bilobates (Mulholland 1986).

Cross forms are abundant in but not exclusive to the panicoid subfamily (Twiss *et al.* 1969; Brown 1984; Mulholland 1989). This type of phytolith has four indented lobes which join at the center. The two noted exceptions, *Aristida* (Chloridoideae) and *Hilaria* (once classified as chloridoid and now a panicoid), both produce lobates (Mulholland 1989). These exceptions arose when grasses were re-classified after the original proposed phytolith morphotype classification.

3) **Chloridoideae** (incl. Eragrostoideae e.g., *Bouteloua* and *Buchloe*) display a variant of the C_4 carboxylation pathway (Jacobs 1987). Most species occur in areas of highly seasonal rainfall or areas which are arid or have irregular rainfall (Jacobs 1987). This subfamily produces abundant saddle morphotypes, which exhibit symmetry in three planes (lateral or 'side', abaxial or 'bottom', and adaxial or 'top'). That is, they have two convex ends and two concave ends (Plates 3.1, 3.28).

The Panicoideae are dominated by lobates and crosses and Chloridoideae are dominated by saddles. Exceptions to this trend constitute less than five percent of the assemblage (Mulholland 1989).

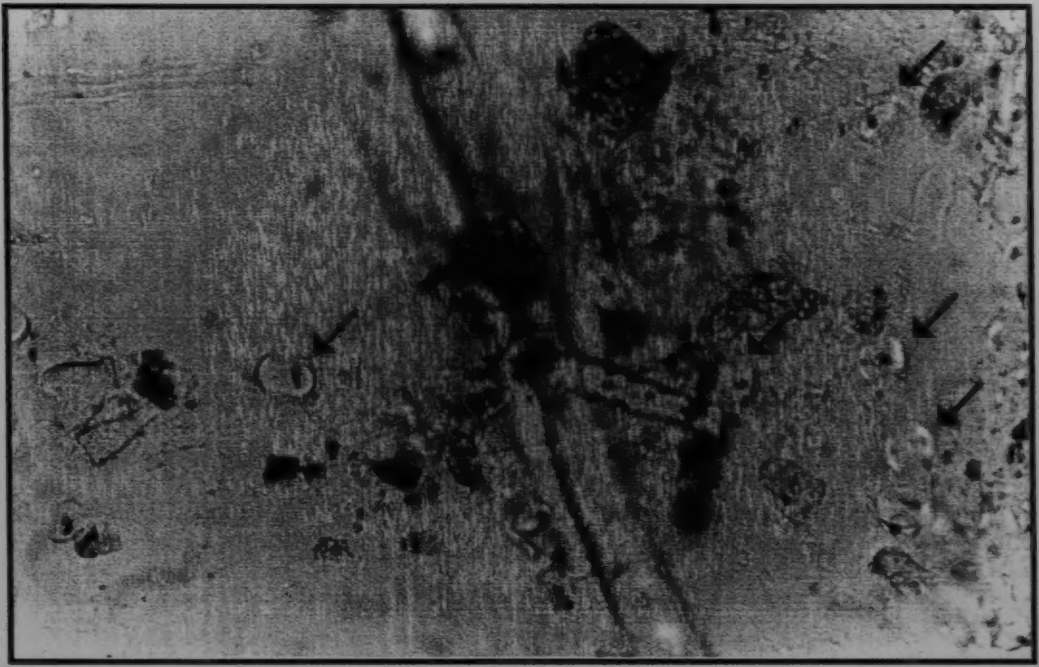


Plate 3.28. Saddles (*Bouteloua sp.*) (400X).

Phytolith morphotype analysis allows distinctions to be made between subfamilies having different environmental tolerances. This makes it a valuable tool in documenting changes in grassland composition. Using ratios of grass short-cell phytoliths, the photosynthetic pathways of parent grass communities may be inferred (Twiss 1992). Brown (1984) in studying 112 grass species common to central North America, suggests that the ratios of different morphotypes could provide information about the relative dominance of C_4 and C_3 carbon pathways (Table 3.1). Relatively higher ratios of Pooideae (C_3) to total Pooideae, Chloridoideae and Panicoideae grasses is indicative of cooler and moister conditions. On the other hand higher ratios of Chloridoideae (C_4) to total grasses suggests arid and semi arid warmer conditions. Similarly, higher ratios of Panicoideae to other grasses may imply warm/moist conditions.

Chapter 4: Phytolith Analysis: Field and Laboratory Procedures

Two sediment profiles were sampled for phytolith analysis. Specific field techniques and laboratory methods were used to best recover and process samples with minimum contamination and maximum utility being the foremost concerns. The samples for the present study were taken from the same sections as those taken by Davis (2001). This was done to facilitate correlation between the paleobotanical information from this study and Davis' (2001) isotope and grain size data in order to offer as complete a picture as possible of paleovegetation and paleoenvironmental conditions in the Lower Salmon River Canyon.

4.1. Hammer Creek (SR-23)

The Hammer Creek (SR-23) section (45° 45' 47" N, 116° 19' 30" E, 480 masl), consists of 4 meters of aeolian silty and sandy loam, was initially identified, described and sampled by Davis (2001) for grain size and stable isotope data (Figure 2.3, Plate 4.1). Located near the Hammer Creek campground, the section was resampled for phytolith analysis.

The Hammer Creek exposure (Figure 4.1) is an east facing exposure is located on the western side of the Salmon River. The basal units are Late Pleistocene alluvium which are capped by Late Pleistocene to Middle Holocene loess, as seen at the Lyon's Bar exposure. The top of this exposure is a non-bedded Late Holocene sandy loess thought to have originated from reworked Late Pleistocene-Holocene alluvium (Davis 2001).

Three soil humate AMS dates from the Hammer Creek exposure are 6,040±620 BP (TO-7816) between 100-110 cm below surface, 13,090±750 BP (TO-7817) between 190-200 cm below surface and 14,930±1030 BP (TO-7818) between 280-290 cm below surface (Davis 2001). An erosional unconformity recorded as a truncated paleosol is evident at 190 cm (Davis 2001). Davis' (2001) interpolated

Plate 4.1. The Hammer Creek Profile (SR-23) (view west, photographed by Brad Somer, 2001).

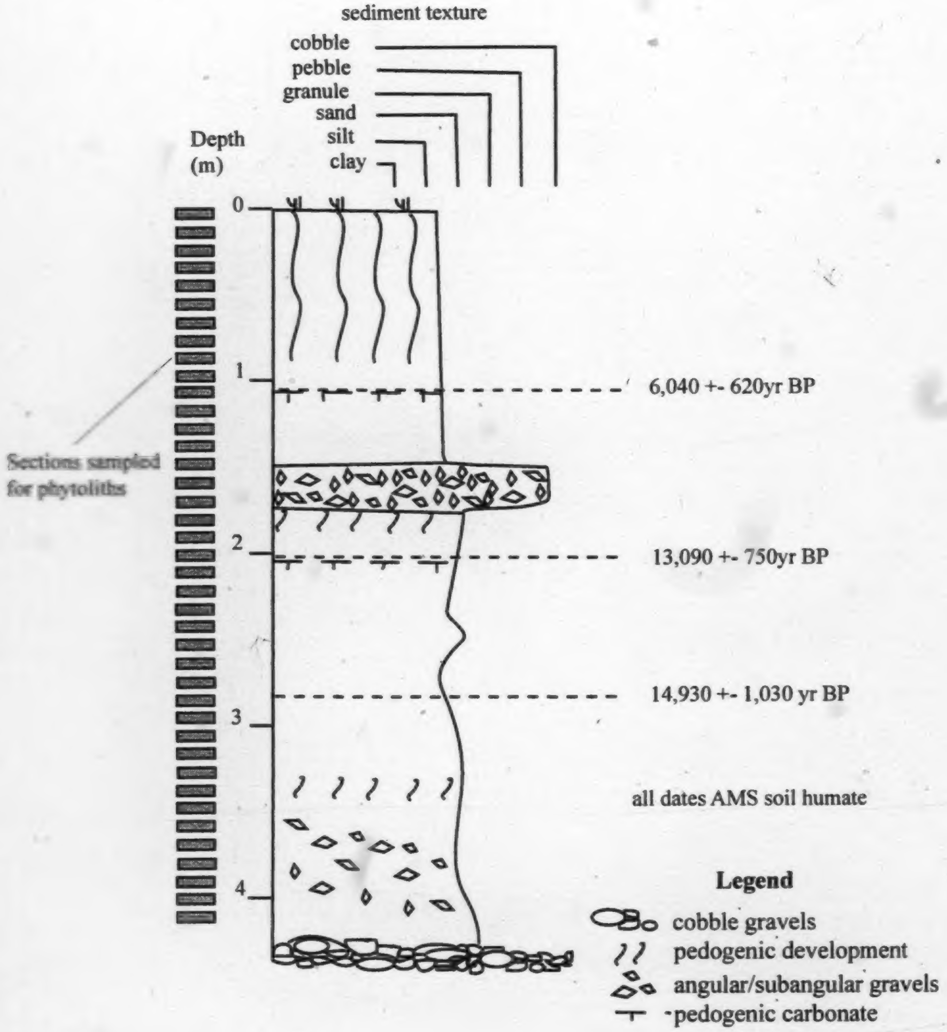

sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
2
3
4
Sections sampled
for phytoliths
6,040 +- 620yr BP
13,090 +- 750yr BP
14,930 +- 1,030 yr BP
all dates AMS soil humate
Legend
cobble gravels
pedogenic development
angular/subangular gravels
pedogenic carbonate

Figure 4.1. Hammer Creek (SR-23) Sediment Profile (adapted from Davis 2001).

chronology was used to provide temporal framework and to retain comparability of the data from this study.

The section was cleaned using a trowel in order to remove modern contamination and expose the stratigraphy before sampling. Little excavation was needed to expose the profile as this had been done previously by Davis. Sediment samples were collected with a trowel and placed in a clean plastic bag, which was immediately sealed. Provenience of the sample was written on each bag. The trowel was wiped clean after each sample had been collected.

Samples were taken at 10 cm intervals, which is small enough to allow for meaningful resolution of the profile without becoming unwieldy. Approximately 100 g samples were collected. This is sufficient for several extractions and allows sampling for any future research needs (Piperno 1988).

4.2. Lyon's Bar (SR-26A and SR-26C)

The Lyon's Bar (SR-26A and SR-26C) section is located approximately four kilometers down river from Hammer Creek (45° 54'N, 116° 21' 30"E, 415 masl) (Figure 2.3). As with Hammer Creek, this profile had been used previously by Davis (2001) for grain size and isotopic analysis of sediments. This section exposes the sediments of a large alluvial fan containing deposits of loess, colluvium, alluvial sand and volcanic tephras (Davis 2001). Two column samples were taken from Lyon's Bar.

The Lyons Bar exposure (Figure 4.2) is a west facing exposure located on the east side of the Salmon River. The base of this exposure is Late Pleistocene alluvium characterized by weakly bedded sand and loamy sand deposited as a result of seasonal overbank sedimentation during glacial conditions ca.15,000-11,400 BP (Davis 2001). This unit is overlain by Late Pleistocene to Middle Holocene Loess which is predominantly silt, lacks bedding and displays weakly developed paleosols. This loess is probably reworked from alluvial sediments, producing a blanketing deposit on landforms adjacent to the Salmon River (Davis 2001). Interspersed are Late

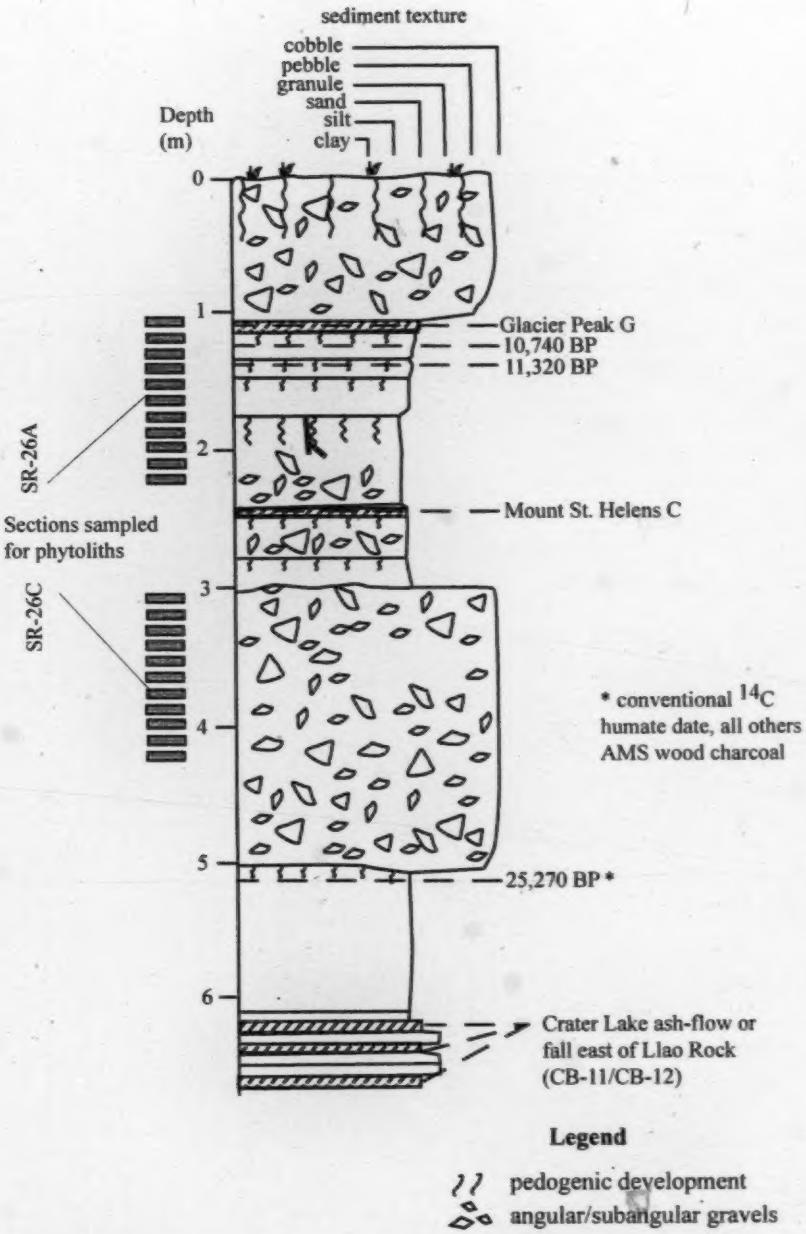

sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
4
5
6
SR-26A
Sections sampled for phytoliths
SR-26C
Glacier Peak G
10,740 BP
11,320 BP
Mount St. Helens C
* conventional ^{14}C humate date, all others AMS wood charcoal
25,270 BP *
Crater Lake ash-flow or fall east of Llao Rock (CB-11/CB-12)
Legend
pedogenic development
angular/subangular gravels

Figure 4.2. Lyons Bar (SR-26) Sediment Profile (adapted from Davis 2001).

Pleistocene to Early Holocene fan gravels originating from bedrock erosion in tributary drainages (Davis 2001).

Two accelerator mass spectrometry (AMS) wood charcoal dates and one conventional ^{14}C soil humate date provide chronology for the Lyons Bar profile. Charcoal samples from paleosols at 120 cm and 140 cm returned dates of 10,740±220 BP (TO-7351) and 11,320±90 BP (TO-7352) while the conventional humate date, from 505-510 cm below surface, resulted in a date of 25,270±530 BP (Tx-9137). Two volcanic tephras are present in the exposure: Mt. St. Helens C (ca. 36,000-37,000 BP; Mullineaux 1986) and Glacier Peak G (ca. 12,750; Porter 1978). While tephras in sediment often act as useful chronostratigraphic markers, this is unfortunately not the case here. The pronounced vertical relief of the canyon and slope erosion affords little opportunity for the tephras to have been incorporated into the stratigraphic record at their place of primary deposition. As a result, tephras in the SR-26 exposure were secondarily deposited and are out of chronological context (Davis 2001).

The area from which the columns were to be taken was cleaned by trowel. A plastic gutter pipe, split longitudinally, was placed over the column and its outline was traced with a trowel. The entire column was then carved out of the exposure and supported using the pipe. Piperno (1988: 113) calls this 'canal sampling.' Columns were wrapped tightly in Saran wrap to maintain their integrity. They were then wrapped again with duct tape to add further support for transportation by raft to a collection point on the river as there was no immediate road access to Lyons bar. The columns were stored in a cool, safe place until they could be processed. This collection technique maintains soil stratigraphy and characteristics and affords greater flexibility when processing the profile in the laboratory. While column sampling is more time consuming in the field, it allows for flexible sampling strategies.

To control for contamination, areas of the column to be sampled were cleaned in the lab and samples were taken only from those sections that were not cracked or otherwise visibly compromised. This method has proved to be very useful in the Calima Valley, Columbia (Piperno 1985) and in this situation as well.

The fact that sediment samples for the Lower Salmon River Canyon profiles are accretionary loess deposits means that the phytolith assemblages represent short periods of vegetation cover, subsequently buried by further loess. This creates a record with finer or continuous resolution compared to sections with long periods of soil development punctuated by depositional events.

4.3. Extraction of Phytoliths from Soil Samples

There are many variations on the laboratory procedures required to extract phytoliths from sediments (see Rovner 1971; Rovner 1972; Bombin 1984; Powers and Gilbertson 1987; Piperno 1988; Pearsall 2000). The basic steps in extraction methods however are the same. Phytoliths must be disaggregated from the associated sediments. Clays especially tend to bind strongly to phytoliths. While this preserves their vertical integrity in the stratigraphy, it causes problems with extraction. Detergent is needed to release phytoliths from clays. Next, organic matter must be removed. Finally, the phytoliths are separated from the remaining sediment, concentrated and mounted for microscopic examination.

The following method, developed by Dr. Brian Kooyman, University of Calgary, was used for Lyon's Bar and Hammer Creek samples. A control was run periodically, using the same extraction steps except without sediment, in order to test for contamination during processing.

1) Soil samples were first sieved through a 0.5 mm geologic sieve to remove coarse material such as roots and rocks; a 5 g portion of sieved sediment was weighed for further processing. Excess material was returned to a sealed container in case this portion was phytolith-poor and processing additional sediment was needed. As the samples were obtained from outside Canada, the sieved portion was placed in a 100 ml graduated beaker and autoclaved to sterilize it. Autoclaving does not affect the phytoliths as the temperatures are much lower than that at which silica is altered.

2) 1 Molar (M) HCl was added to the sediment in a fume hood to remove carbonates. Samples were shaken and HCl was added until the bubbling reaction had

stopped. The contents of the beaker were then poured into a centrifuge tube, washed using distilled water and the wash was added to the tube. Disposable centrifuge tubes were used in order to prevent cross-contamination. Tubes were placed into a tabletop centrifuge and spun for five minutes at 3000 rpm. Supernatant was poured off and the process of washing and centrifuging was repeated twice more to remove all the HCl from the solution (3 times in total). At this point, all carbonates have been removed.

3) Disaggregation of clays was done in a Calgon detergent solution (50 g/L of sodium phosphate). Phytoliths are often bound to clays and other fine particles and it is necessary to break these bonds. Detergents, such as Calgon, have proven to be effective in doing this. Vigorous agitation was done to disaggregate the clays. Samples were left in the Calgon solution for one hour and agitated periodically. Piperno (1988) found that skipping this step decreased phytolith yield dramatically.

After the Calgon treatment, the beakers were filled to 400 ml with distilled water. The samples were stirred vigorously and distilled water added to a depth of 8 cm. They were then left to settle for one hour. This was done to separate out various grain size fractions such as sand and silt which settle at 8 cm/hr. This step removed silt and clay particles which may result in 'dirty' slides thereby complicating the counting of morphotypes.

One hour later, the supernatant was siphoned off with a syringe, taking care not to suck up any of the sediment at the bottom of the beaker. This process was repeated (typically five or six times) until the supernatant was more or less clear, indicating that most clays and silts had been removed. After this, the sediment was left to dry.

Up to this point, carbonates, clays and fine silts (5-20 μm) had been removed (basically everything siphoned off was <5 microns). Some small phytoliths may have been removed with the siphoning as well. These are typically too small to be identifiable as anything more than minute opal silica bodies. What remains are the larger and heavier materials (sands), which include the majority of phytoliths

4) Next was chemical flotation. Phytoliths have a specific gravity of ~2.29 while quartz, sand grains, have a specific gravity of 2.65 (Jones and Beavers 1963). Sodium polytungstate [$3Na_2\bullet(WO_4\bullet9WO_3)\bullet H_20$] formula with a specific gravity of

2.3 was used as the heavy liquid to separate phytoliths from the remaining sediment. As it is an expensive chemical it was recycled by pouring it through filter paper into a clean container and allowed to evaporate to dryness. At this point it could be rehydrated to the appropriate specific gravity.

3 mL of sodium polytungstate was added to the centrifuge tube in order for there to be sufficient 'fall space' for the sediments in the solution when it was later centrifuged. A small amount of dried sediment was added and the tube was capped, shaken and centrifuged for five minutes at 3000 rpm.

The supernatant, which contained the phytoliths, was added to a new centrifuge tube and diluted with distilled water. This lowered the specific gravity of the sodium polytungstate allowing the phytoliths to settle. The diluted solution was centrifuged again causing the phytoliths to sink to the bottom in what is essentially a distilled water bath. The liquid was then poured off and more distilled water was added and centrifuged. This step was repeated twice more in order to remove all the sodium polytungstate and to concentrate the phytoliths.

5) At this point, the phytoliths had been separated from the other constituents and were ready for mounting. A microscope slide was cleaned using a Kimwipe and labeled. A small metal scoop was used to place an amount of wet residue onto the slide. A few drops of distilled water were added and the wetted residue was swirled in order to spread the sample over the slide. The slide was then allowed to dry in the fume hood. When the sample was dry, Entellan (manufactured by Mikroskopie Inc.) was placed on the slide with a wooden skewer and then covered with a cover slip. Two slides were made for each sample. Slides were ready to be examined as soon as the Entellan had set, usually in two or three hours.

4.4. Counting Procedures

After a thorough study of Eccleston's (1999) comparative material and that available at the University of Calgary, a regional counting methodology was adapted with the specific goal of using phytolith morphotype frequencies to aid in paleoenvironmental reconstruction. Fredlund (1993) and Fredlund and Tieszen (1994) modified the counting scheme developed by Twiss *et al*. (1969). Their scheme was used as a model for Poaceae phytolith counting in this study as it proved to be effective. Also, Eccleston's (1999) non-grass counting scheme was used as she identified a number of diagnostic phytoliths on the Columbia Plateau. Appendix A contains the counting methodology used in this project.

Slides were examined using a Leitz Dialux microscope with low (25X), medium (40X), and oil immersion (100X) objectives. Slides were systematically scanned at 250X. This magnification was sufficiently strong to be able to recognize all diagnostic phytolith shapes. When necessary to confirm phytolith identification, the morphology was examined at higher magnification (400X).

Between 200 and 300 diagnostic phytolith types were counted on each slide with grass short-cell counts always numbering over 100 and usually over 125. A 200 count is a standard minimum count in both pollen and phytolith analysis as it can be demonstrated to give results representative of the phytolith assemblage (Pearsall 2000).

Chapter 5: Late Pleistocene/Holocene Environments: Phytolith Records, Lower Salmon River Canyon, Idaho

5.1. Results of Analysis

The chronology of Lyons Bar and Hammer Creek overlap (see Figure 5.1) and together they provide a phytolith record that extends from ca. 21,000 BP to the present, with gaps between 17,600-17,000 BP and 9,600-7,200 BP. All phytolith assemblages from Lyon's Bar and Hammer Creek exposures are dominated by 55% to 95% C_3 grass morphotypes. The phytolith record from Hammer Creek contains a sterile zone.

5.1.2. Statistical Procedures

Phytolith percent diagrams were constructed to facilitate description, interpretation and correlation of phytolith levels. Each diagram was divided into phytolith zones determined by the Constrained Single Link Method (CSLM). CSLM is a 'city block' or 'Manhattan' metric in which a dissimilarity matrix is generated as a measure of differences between stratigraphically adjacent phytolith spectra (Birks and Gordon 1985; Grimm 1988). An agglomerative algorithm is then applied to cluster adjacent, similar phytolith levels. Zones were labeled with Roman numerals from earliest to latest. Furthermore, timelines for upper and lower zone boundaries are interpolated from available ^{14}C dates.

To examine associations of phytolith types Principal Components Analysis (PCA) was used. This is a commonly used tool in fossil pollen analysis but it has not been previously applied in phytolith paleoenvironmental studies (see Birks *et al.* 1975; Ritchie 1977; Ritchie and Yarranton 1978; MacDonald and Ritchie 1986, for example). PCA is a series of calculations by which complex multivariate data (in this case many individual samples containing multiple phytolith morphotypes) can be reduced to a two or three-dimensional representation of covariance. It is a multidimensional scaling method that is capable of representing a number of

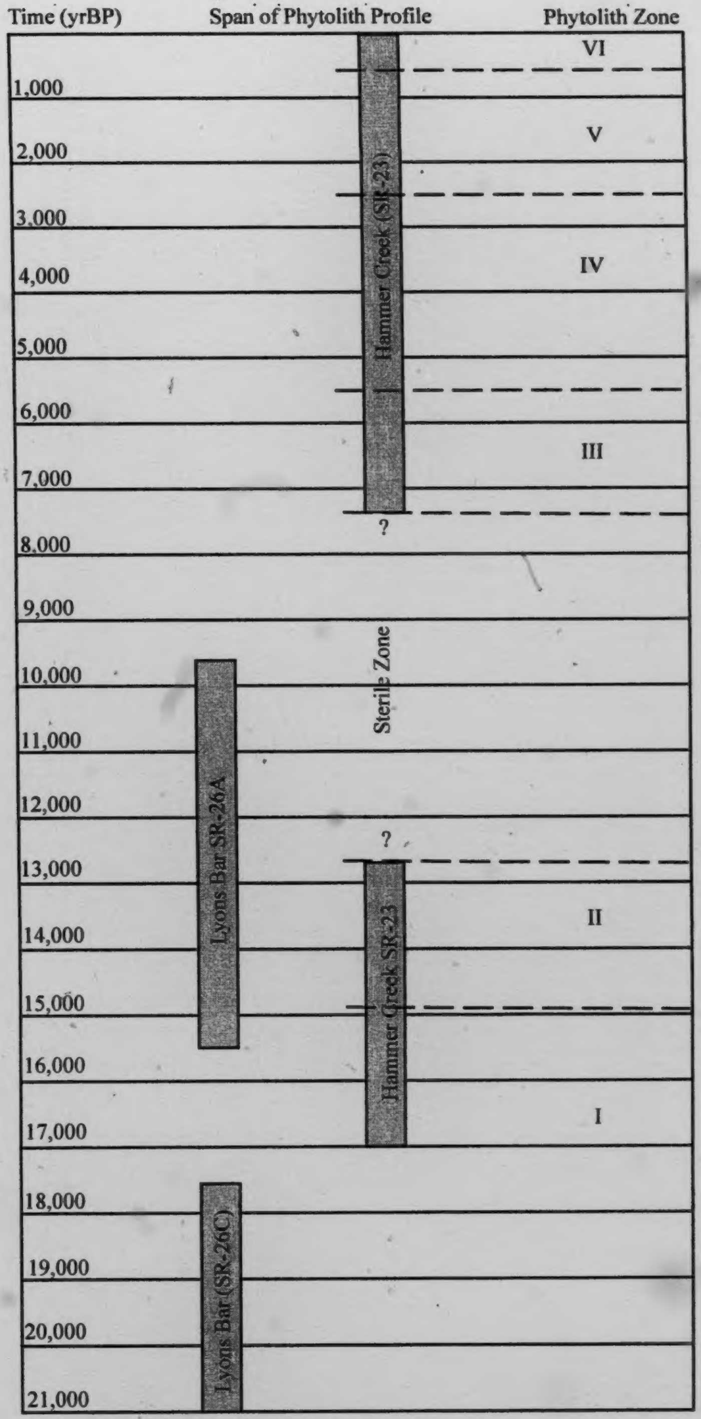


Figure 5.1. Chronological Span of Phytolith Samples and Phytolith Zones (separated by dashed lines).

populations as points in a coordinate system where the distance between points conveys a degree of similarity or dissimilarity (Prentice 1980). PCA identifies axes (called components) that describe the major source of variation (e.g., the first component accounts for the maximum possible variance between a set of variables, the second accounts for the second largest variance and so on). 'Ordinary' PCA employing a correlation matrix was conducted on the data from Lyons Bar and Hammer Creek using the SSPS ver.10 software package (SSPS Inc., Illinois). The results are 'principle component ordinates' which may be viewed as approximations of the rate and nature of vegetation change as well as a measure of assemblage homo- or heterogeneity (Ritchie 1977; MacDonald and Ritchie 1986). Detailed results and a more comprehensive discussion of these calculations can be found in Appendix B.

5.1.3. Lyons Bar (SR-26)

Twenty-three sediment samples were processed from the Lyons Bar exposure. All produced abundant quantities of phytoliths whose preservation was excellent throughout. A total of 28 distinct morphotypes were found, representing five non-grass families, three non-grass species, and one dicotyledonous form. Additionally, the family Poaceae and three subfamilies of Poaceae could be distinguished. The phytolith record of the Lyons Bar profile spans ca. 21,000-17,600 BP and 15,400-9,600 BP.

Phytolith Spectra (410-300 cm and 210-110 cm) (ca. 21,000-17,000 BP and 15,4000-9,600 BP)

The phytolith assemblage displays little variation and therefore no zones were established (Figure 5.2). Pooid forms (C_3 grasses) dominate, comprising 55-70% of total forms. Panicoid and Chloridoid (C_4 grasses) forms each comprise between 2-10%. The non-grass phytolith components include *Picea/Pinus ponderosa* (5-9%) and *Picea/Pinus monticola* (<5%) forms. As morphotypes specific to *Pinus ponderosa* are

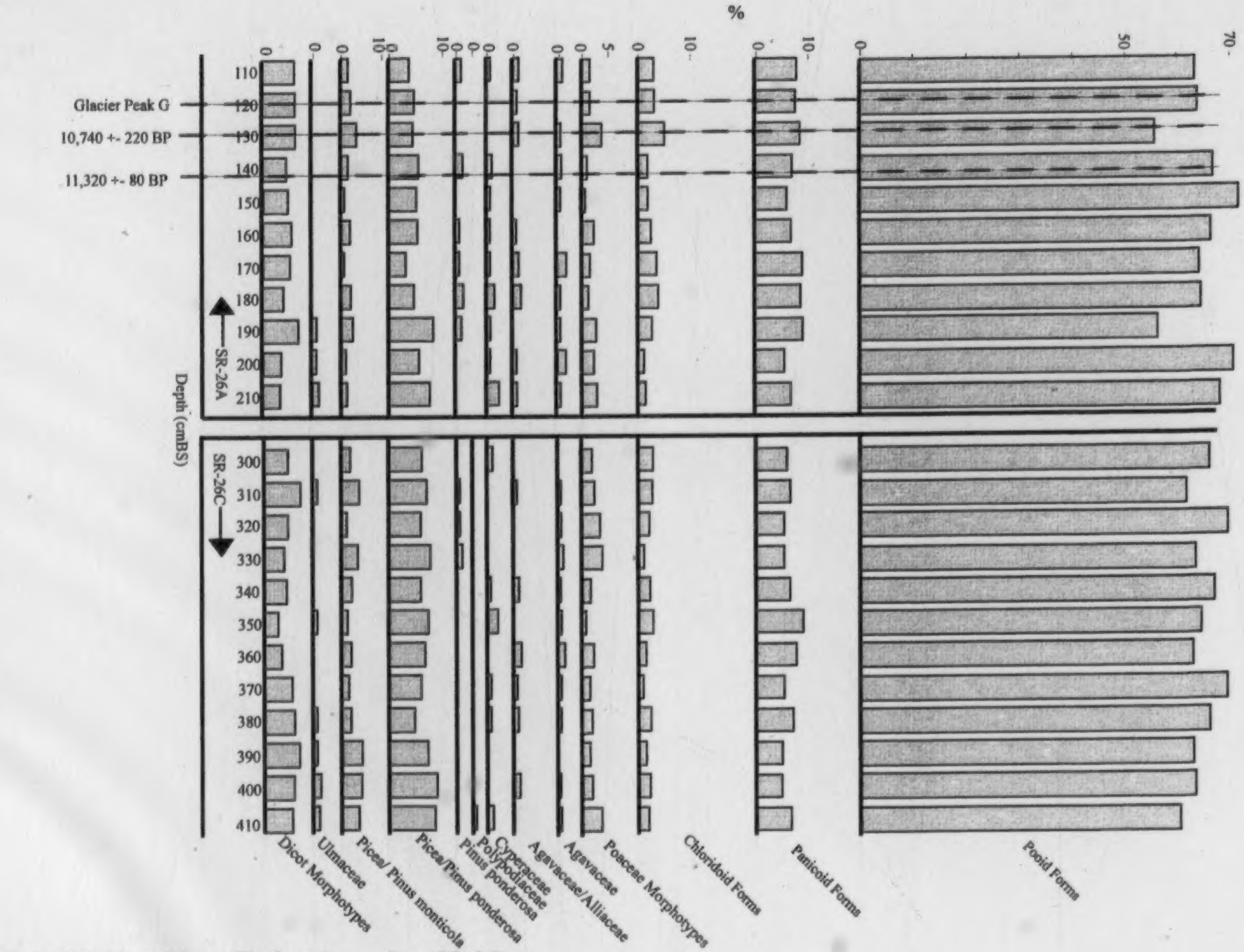


Figure 5.2. Phytolith profile from Lyons Bar (SR-26).

largely absent, this suggests that *Picea/Pinus ponderosa* forms primarily represent *Picea* and not *Pinus ponderosa*.

5.1.4. Hammer Creek (SR-23)

Forty-one sediment samples from the Hammer Creek exposure were processed. Thirty-five produced abundant quantities of phytoliths whose preservation was excellent. Six did not yield adequate phytolith numbers. These sterile samples come from 190-140 cm and 120 cm, between phytolith Zones II and III (Figure 5.3). This coincides with a coarse grained and gravelly section in the profile immediately above an erosional unconformity (Figure 4.1).

A total of 40 distinct morphotypes were present representing the family Poaceae, three Poaceae subfamilies, four non-grass families, five non-grass species, and one general dicotyledonous form. From dates determined from the interpolated chronology, this phytolith record spans an interval from 17,000-12,800 BP and 7,200 BP-present.

Zone I (400-300 cm) (ca. 17,000-14,900 BP)

Zone I is dominated by pooid forms (C_3 grasses), over 70%, with minor components of panicoid forms (C_4 mesic grasses), 3% to 7%, and chloridoid forms (C_4 xeric grasses) fluctuating at <3%. From 340-320 cm (16,800-15,800 BP), chloridoid forms and pooid forms decline in abundance with an increase and subsequent return to 'normal' frequencies of panicoid forms. A non-grass phytolith component of *Picea/Pinus ponderosa* (<6%) and *Picea/Pinus monticola* (<5%) fluctuates throughout Zone I. Phytolith morphotypes specific to *Pinus ponderosa* are present but only in small numbers suggesting a predominantly *Picea* and/or *Pinus monticola* non-grass vegetative cover.

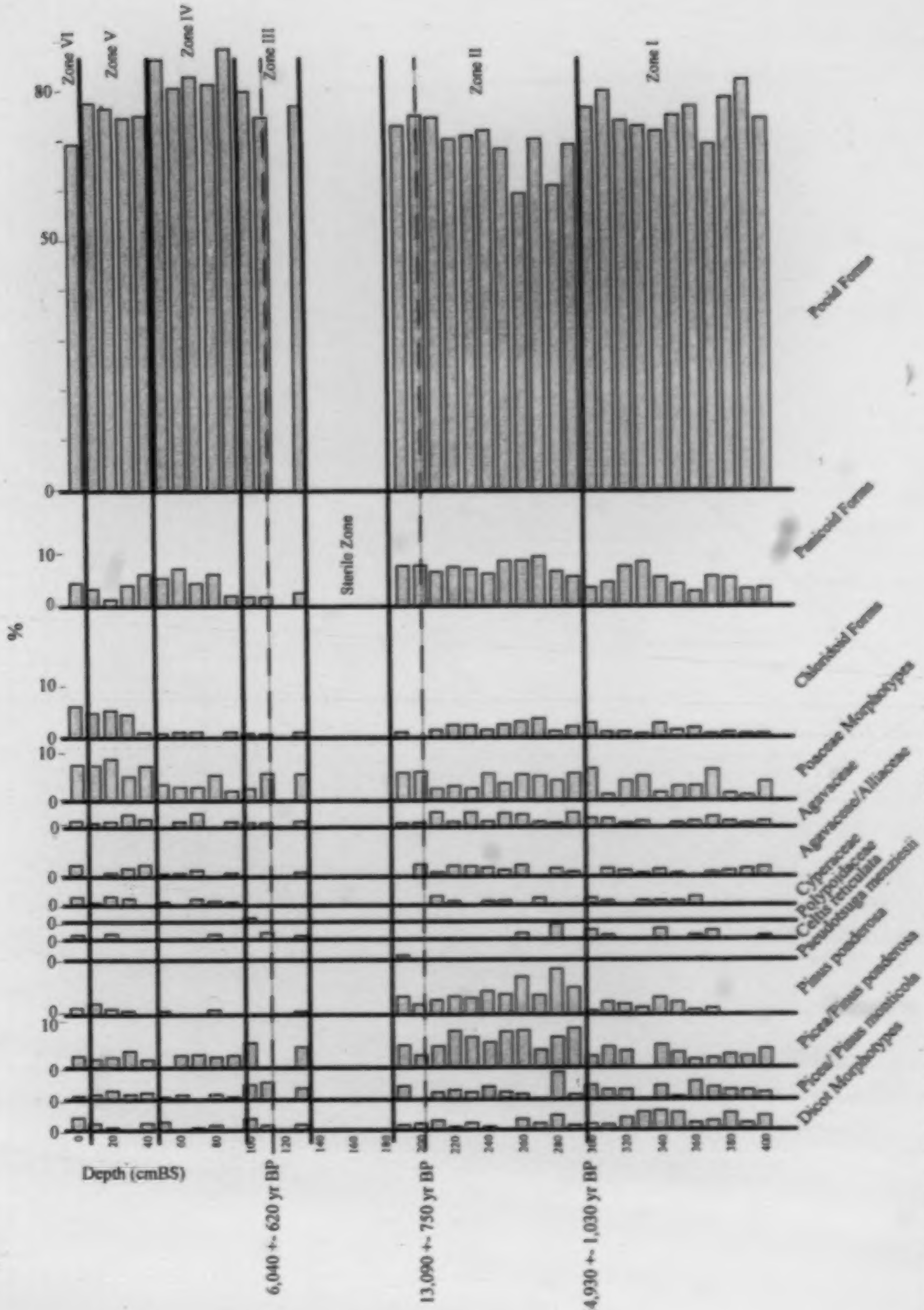


Figure 5.3. Phytolith profile from Hammer Creek (SR-23).

Zone II (290-190 cm) (14,900-12,700 BP)

Zone II is characterized by a decrease in pooid forms (C_3 grasses), <70%, as well as increased and relatively stable frequencies of panicoid forms (C_4 mesic grasses), 7-10% and chloridoid forms (C_4 xeric grasses), >4%. Chloridoid and panicoid forms rise to levels similar to those seen in the previous zone from 340-320 cm. Of the non-grass phytolith component, *Pinus ponderosa* (3-10%) and *Picea/Pinus ponderosa* (3-10%) forms show marked increases. *Pinus ponderosa* morphotypes peak in the beginning of this zone but decline by the upper boundary.

Zone III (130-100 cm) (7,200-5,500 BP)

Zone III is characterized by pooid forms (C_3 grasses) reaching ~75%. Panicoid (C_4 mesic grasses) (~3%) and chloridoid (C_4 xeric grasses) (<1%) forms decline. Non-grass phytolith forms are also conspicuously scarce with *Picea/Pinus ponderosa* (~4%) types comprising the majority of this class of phytolith morphotypes. Morphotypes specific to *Pinus ponderosa* are virtually absent in this zone in contrast to their relative abundance in Zone II.

Zone IV (90 – 50 cm) (5,500-2,400 BP)

Zone IV begins with pooid forms (C_3 grasses) reaching ≥80%, the highest levels in the entire profile. Panicoid forms (C_4 mesic grasses) rise to 3-5% and there is a near absence of chloridoid (C_4 xeric grasses) morphotypes. The non-grass phytolith component again is sparse. *Picea/Pinus ponderosa* forms (~2%) are the most abundant of the non-grass phytoliths. Forms specific to *Pinus ponderosa* are rare suggesting *Picea* may have been a more influential phytolith contributor.

Zone V (40 – 10 cm) (2,400 BP to 550 BP)

Pooid morphotypes continue to dominate the phytoliths assemblages in Zone V. There is an increase in chloridoid forms (C_4 xeric grasses) to ~5% in this zone with decreases in both pooid (C_3 grasses) (~75%) and panicoid forms (C_4 mesic grasses) (<5%). Chloridoid short cell phytoliths are at their highest levels in the profile. Again, non-grass phytolith morphotypes are rare.

Zone VI (Modern assemblage) (0 cm)

Pooid forms (C_3 grasses) comprise less than 70% of total morphotypes while panicoid (C_4 mesic grasses) and chloridoid forms (C_4 xeric grasses) each contribute ~5%. Poaceae forms continue to predominate and non-grass phytolith morphotypes are rare. While *Picea/Pinus ponderosa* and specific *Pinus ponderosa* morphotypes are present, they are not as frequent as they were lower in the profile.

5.2. Discussion

5.2.1. Lyons Bar

Phytolith Spectra (410-300 cm and 210-110 cm) - SR-26A and SR-26C span the Late Pleistocene period (ca. 21,000-17,600 BP and 15,400-9,600 BP) (Figure 5.2). Relatively constant levels of panicoid and chloridoid forms indicate a minor, stable C_4 component in a predominantly C_3 grassland. Major components of the non-grass taxa are *Picea/Pinus ponderosa* and *Picea/Pinus monticola* morphotypes. Since *Pinus ponderosa* specific morphotypes are virtually absent, it is safe to assume the *Picea/Pinus ponderosa* morphotypes actually represent primarily *Picea* forms. Because there are no *Pinus monticola*-specific forms, a similar differentiation for the *Picea/Pinus monticola* morphotype could not be made. The results would indicate that *Picea* comprised the majority of non-grass cover. There are also relatively stable levels of general dicotyledonous forms throughout the profiles indicating a constant woodland component. Together these indicate the presence of a greater woodland environment than seen at present (see the modern assemblage at Hammer Creek). These data suggest a predominantly spruce woodland with a C_3 grassland component during the Late Pleistocene-Early Holocene.

The phytolith record from SR-26A and SR-26C characterizes the riparian vegetation during Late Wisconsin glacial conditions. Because the majority of morphotypes are pooid forms, they tend to mask variation in other assemblage components. Therefore, they were excluded from PCA calculations knowing full well that any changes observed occurred in a C_3 grassland environment. Non-grass species are poor phytolith producers so even small changes in their distribution may represent important changes in vegetation. Results of PCA calculations applied to the spectra of diagnostic phytolith morphotypes are approximations of the location of a phytolith form in a two dimensional depiction of dissimilarity (Figure 5.4) (Ritchie 1977; MacDonald and Ritchie 1986). The indistinct woodland/grassland delineation in SR-26 data suggests that the assemblage was a largely homogenous mixture through time. That is, there are no vectors which would define a predominantly woodland or grassland component. In a similar manner, the variants (i.e., phytolith spectra from each level) can be calculated and plotted to help explain the direction and rate of change (Figure 5.5). This, along with the previous calculation, allows the detection of components varying between samples. The large overlap in the SR-26A and SR-26C ordinants indicates little difference in the data. In other words, SR-26A and SR-26C have similar phytolith assemblages. This supports the fact that no distinct phytolith zones could be distinguished from qualitative analysis of the phytolith profile and CLSM calculations.

In order to describe the changes in assemblage through time, a time-trend diagram was created (MacDonald and Ritchie 1986). This was done by calculating the mean of each phytolith zone (the centroid) together with one standard deviation (the cross hairs) and configuring the timeline to represent these points (Figure 5.6). Centroids were joined by a solid line to which extrapolated ^{14}C ages were added to

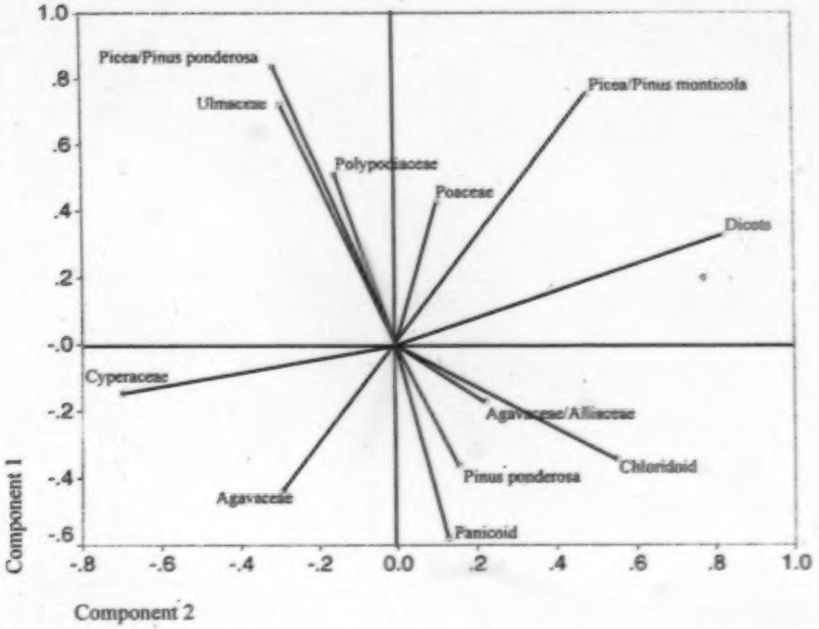


Figure 5.4. Ordination of the twelve components (SR-26 phytolith morphotypes).

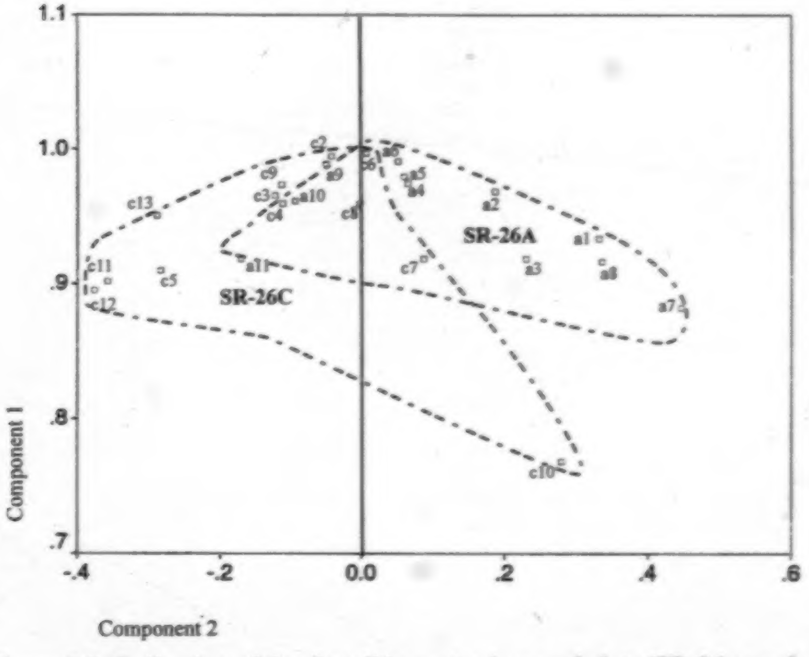


Figure 5.5. Ordination of the phytolith spectra in sample lots (SR-26 samples).

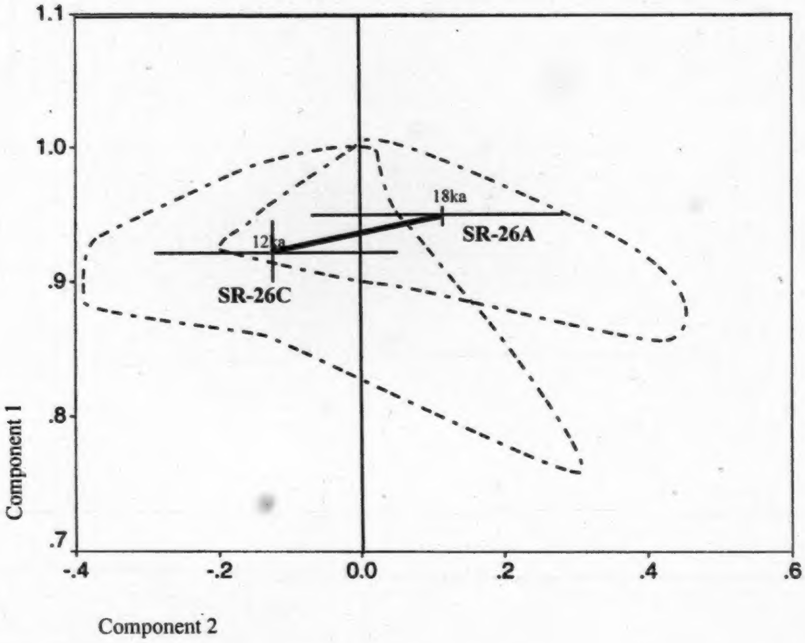


Figure 5.6. SR-26 timeline and phytolith sample plots.

indicate time progression. This line was integrated into the PCA ordinate data. This process assists in interpreting the direction and timeline for changes occurring in a set of ordinants. The line is a chronosequence of phytolith spectra frequency changes. This analysis also shows the similarity of the SR-26 assemblages. There was little change over eleven millennia. The predominance of C_3 grasses and the presence of *Picea* in SR-26 data points to a relatively cool and moist environment.

At the present time, two species of spruce predominate in the Pacific Northwest Rocky Mountains: *Picea engelmannii* and *Picea pungens*. Both are restricted to wet and cold habitats (Uchytil 1991; Pavek 1993). Engelmann spruce is found in some of the highest and coldest environments in the western United States, areas with long cold winters and short cool summers. Modern environmental conditions on the Columbia Plateau are within the *Picea engelmannii* tolerance range though it is usually found at higher elevations, such as the mountainous ranges to the east at the headwaters of the Salmon River. The climatic tolerances for this species are shown in Table 5.1. For comparison, the closest canyon bottom weather station to the study area is at Riggins, approximately 40 km upstream. Engelmann spruce is a component of the forest cover between its lowest occurrence at 610 m (where it is found only in cold, moist valley bottoms) to 2,286 m where it is only a minor component making the treeline (Uchytil 1991). While modern temperatures in the canyon bottom would be suitable for *Picea engelmannii*, precipitation is a limiting factor. There are presently no spruce trees in the Lower Salmon River Canyon. Sparse, isolated stands are located in riparian areas above 1220 masl, the closest to the study area being 10 km away on the Joseph Plains to the west and at the headwaters of Whitebird Creek to the east (David Sisson & Craig Johnson, personal communication). The second spruce species, *Picea pungens*, is currently restricted to the central and southern Rocky Mountains and is found only in southeastern Idaho between 1,982 and 2,560 masl. The closest stand of this species is approximately 550 km away. The climatic tolerances for this species is shown in Table 5.1. Comparison of the modern spruce bioclimate and paleovegetation records indicates a cooler and more moist paleoclimate than at present through the Lyons Bar sequence, the Late Wisconsin glacial.

Table 5.1. Modern climate conditions in the Lower Salmon River Canyon and species bioclimate (Thompson *et al.* 2000; Western Regional Climate Center 2000).

	Riggins	*Picea engelmannii*	*Picea pungens*	*Pinus ponderosa*
Mean annual temperature (°C).	5.5 - 19	–7 - 10	0 - 10	0 - 25
Mean January temperature (°C).	–2.5 - 5	–20 - 0	–5 - –10	–15 - 15
Mean June temperature (°C).	11 - 27	5 - 20	10 - 20	10 - 30
Annual precipitation (mm).	430	500 - 1,400	500 - 1,000	300 -1,200

The uniform nature of the phytolith record indicates the presence of mixed grassland vegetation dominated by C_3 pooid taxa. *Picea* and perhaps *Pinus monticola* made up the arboreal element in what was otherwise and open vegetation. Today, *Pinus monticola* and *Picea engelmannii* are associated in subalpine forests in some areas of the Pacific Northwest, specifically the western slopes of the Sierra Nevada (Griffith 1992). This is vegetation indicative of a cooler environment than today's with a significant amount of available moisture. Since no trends in phytolith composition are discernable one must assume that there was stable vegetation cover at this site from ca. 21,000-17,500 BP and 15,400-9,600 BP.

5.2.2. Hammer Creek (SR-23)

Phytolith Zone I (400-300 cm) (17,000-14,900 BP) – The base of the SR-23 profile records a pooid (C_3) grassland with a fluctuating C_4 component consisting mostly of panicoid forms. The major portion of the non-grass cover was comprised of *Picea/Pinus ponderosa* and *Picea/Pinus monticola* forms. Relatively low frequencies of *Pinus ponderosa*-specific morphotypes indicate that this was a minor component of the non-grass cover through most of this zone, which suggests that *Picea* likely dominated the non-grass ground cover. It is also possible that *Pinus monticola* was present but a measure of this species' influence on phytolith morphotype frequencies is tentative as phytoliths diagnostic of this species are also found in *Picea*.

A cool and relatively moist climate is inferred during the later half of the Late Wisconsin glacial period. The fluctuating C_4 component suggests the possibility of minor fluctuations in moisture conditions.

Phytolith Zone II (290-190 cm) (14,900-12,700 BP) exhibits decreasing pooid (C_3) frequency. C_4 grass morphotypes are more frequent, especially panicoid grasses which are at their highest levels in the profile. *Picea/Pinus ponderosa* and specific *Pinus ponderosa* morphotypes are also at their highest levels at the beginning of this zone then decline through the duration. The *Pinus ponderosa* component in the woodland increased along with arid adapted grasses during the Late Wisconsin period.

Today *Pinus ponderosa*, being a drought tolerant species, typically occupies the transition zone between grassland and forest. Characteristically, stands are in warm and dry locations between 100 and 1,500 masl with a mean stand elevation of 800 masl (Thompson *et al.* 2000, Habeck 1992). *Pinus ponderosa*'s modern distribution includes the Columbia Plateau (Table 5.1). Increased frequency of non-grass cover and the nature of changes in grass subfamily frequencies suggest warmer and more arid conditions than previously but still more moist than today.

Elias (1996) indicates, in his paleotemperature reconstructions from fossil beetle assemblages in the Northern Rocky Mountains, that Late Pleistocene-Early Holocene temperatures started rising ca. 13,200 BP and would have been several degrees warmer than present by ca. 10,000 BP.

Hiatus (190-140 cm) No significant phytolith numbers were recovered between Zone II and III. The beginning and end date for this haitus has been estimated from the interpolated chronology which was applied to the rest of the profile. In the stratigraphic profile, this is immediately after the erosional unconformity, when coarse grain sediments were deposited (Figure 5.3). This may have been a period during which significant soil formation did not take place. The erosional event along with the deposition of sediment types less likely to bind to phytoliths may also account for the absence of phytoliths.

Phytolith Zone III (130-100 cm) (7,200-5,500 BP) - Pooid (C_3) forms dominate while C_4 morphotypes drop to their lowest levels in the entire profile. The near absence of *Pinus ponderosa*-specific phytolith morphotypes is also notable. There was a slight resurgence of *Picea/Pinus monticola* morphotypes. The paucity of Ponderosa pine morphotypes when compared to the previous zone also indicates a change in woodland species composition to a more spruce/western white pine dominated arboreal component. The vegetation cover during Zone III was largely a mesic grassland with a more sparse woodland component than seen in the two previous phytolith zones. This suggests a reversal of climatic conditions from the warm and arid conditions seen in the previous zone to relatively cooler and more moist conditions.

Phytolith Zone IV (90-50 cm) (5,500-2,400 BP) - Pooid (C_3) grass forms reach their highest levels in the entire profile during this zone. This, together with the low levels of C_4 grasses, suggests a cool, mesic grassland environment. Although *Picea/Pinus ponderosa* forms make up the majority of the non-grass component, the total frequency of non-grass forms is less than seen previously in the profile indicating that these taxa were no longer as important as they once were. This zone reflects a continuation of the cool and moist trend of the previous zone and probably indicates vegetative response to a widespread climatic cooling, the Neoglacial, which began as early as 5,000 BP and ended sometime after 3,000 BP in the Washington Cascade Range and on the Columbia Plateau (Davis 1988).

Phytolith Zone V (40-10 cm) (2,400-550 BP) - The maximum frequencies of Chloridoid (C_4 xeric) forms and the paucity of non-grass morphotypes suggests a more xeric grassland than previously and a period of aridity and warmth.

Zone V shows no evidence of a Medieval Warm Period - Little Ice Age oscillation. The Little Ice Age (LIA) period of reduced summer temperatures and increased precipitation persisted from the 15th-19th century (Reasoner and Huber 1999; Luckman 2000). The LIA was not a synchronous, global event of similar environmental manifestations as there was considerable variability in the timing and extent of climatic response (Luckman 2000). The Lower Salmon River Canyon phytolith record provides no evidence of a LIA influence on the vegetation.

Phytolith Zone VI (0 cm) (modern assemblage) - The phytolith assemblage represents the modern vegetation. The 'Palouse Prairie' is a predominantly C_3 grassland in which the dominant species are grasses such as *Agropyron spicatum*, *Festuca idahoensis* and *Poa secunda* (Gould and Shaw 1983). Again, non-grass morphotypes were scarce compared to earlier zones, with the most frequent morphotype being *Pinus ponderosa*. The arboreal component of the Palouse Prairie is comprised of sparse stands of *Pinus ponderosa* and *Pseudotsuga menziesii* typically constrained to drainages (Kuchler 1964). The phytolith assemblage in this zone indicates a continuation of the warm and dry climate of Phytolith Zone V.

As was the case with Lyons Bar (SR-26), the majority of morphotypes present at Hammer Creek (SR-23) were pooid forms. Because they tended to mask variations in other morphotypes, they were excluded from PCA calculations recognizing that a predominantly C_3 grassland environment persisted. PCA calculations for components of variance (i.e., spectra of diagnostic phytolith morphotypes), are approximations of the location of phytolith taxa in a two dimensional depiction of dissimilarity (Ritchie 1977; MacDonald and Ritchie 1986). Woodland and grassland taxa segregated into distinct clusters (Figure 5.7). That is, there were vectors defining a greater woodland or grassland component. Similarly, the variants, phytolith spectra, were calculated and plotted to show their direction and rate of change (Figure 5.8). Phytolith spectra, the population of morphotypes from the samples levels, clustered in the phytolith zones originally delineated by CSLM analysis. The zones also serve to document the nature and rate of change in phytolith levels. To achieve this, the phytolith zones were linked chronologically using the same techniques described for the SR-26 data and the results were integrated into the PCA ordinate data. The resulting line is a chronosequence of phytolith spectra frequency changes showing a gradual but persistent change from woodland taxa (phytolith Zones I through IV) to a predominantly grassland composition (phytolith Zones V and VI) (Figure 5.9).

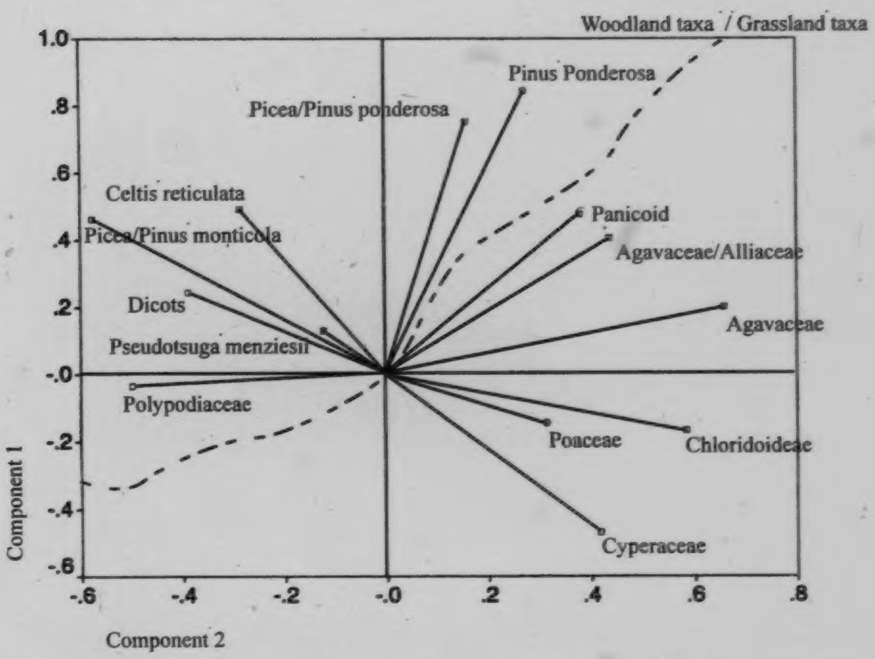


Figure 5.7. Ordination of the thirteen components (SR-23 phytolith morphotypes).

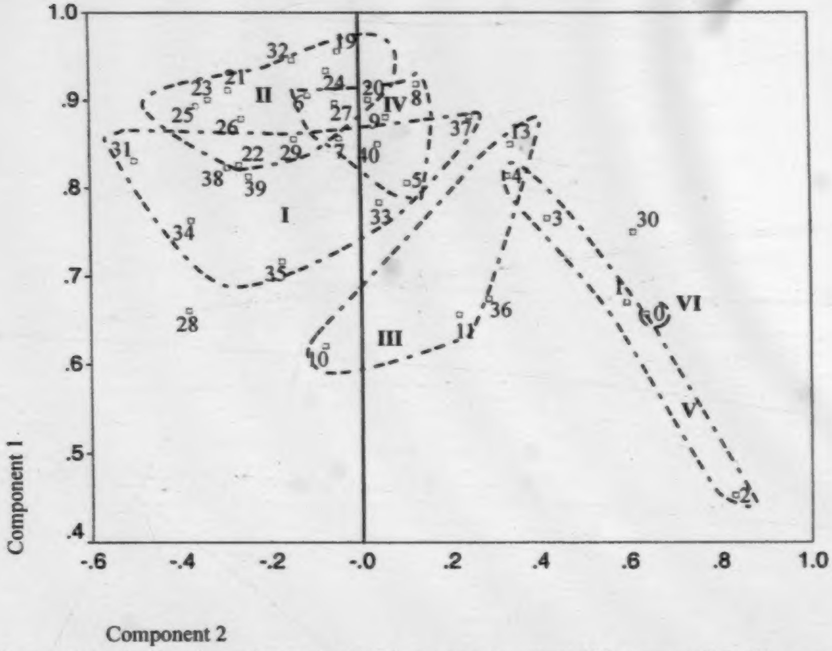


Figure 5.8. Ordination of the phytolith spectra in phytolith zones (SR-23 samples, the dotted lines and Roman Numerals indicate established phytolith zones).

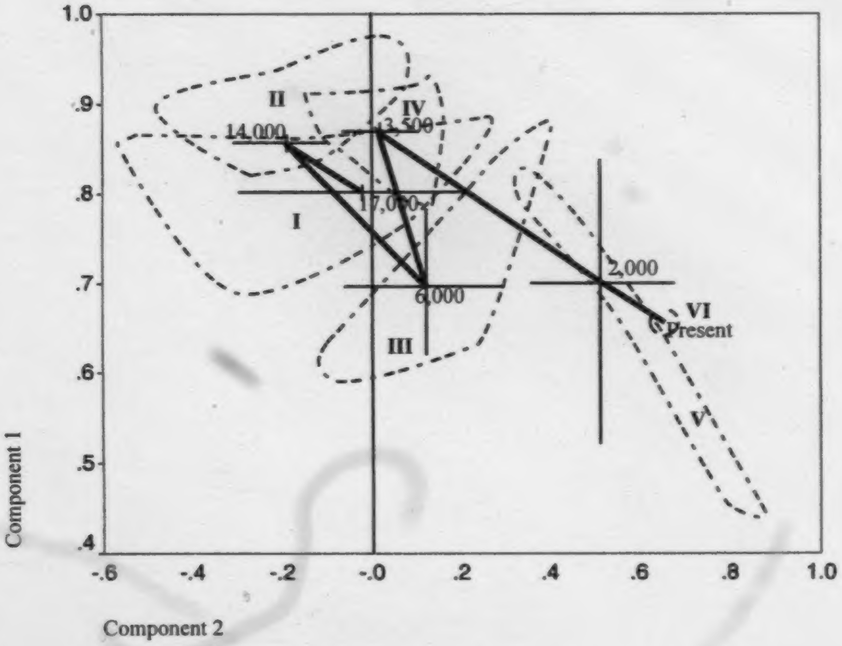


Figure 5.9. SR-23 timeline and phytolith zonation.

Generally, the presence of *Picea*, C_3 grasses and higher proportions of dicotyledonous forms characterized cool/moist conditions. Higher C_4 grass frequencies and *Pinus ponderosa* forms along with an overall decrease in arboreal morphotypes indicate warm and more arid conditions. For Phytolith Zone I, *Picea/Pinus monticola* and *Picea/Pinus ponderosa* account for most of the variance. By 14,000 BP there is a greater presence of woodland taxa. From 14,000 to 6,000 BP, Zone II to Zone III, *Pinus ponderosa* and grassland taxa are becoming more important components of the phytolith assemblage. This trend reverses from 6,000 to 3,500 BP, Zone III and Zone IV, with the appearance of more woodland taxa, most importantly *Picea/Pinus ponderosa* forms. This shift probably represents the aforementioned Neoglacial 'signature' in the Lower Salmon River Canyon. From 3,500 BP to the present, Zone V to Zone VI, increasing frequencies of grassland taxa, especially Panicoid forms, account for the variation in the phytolith spectra. At approximately 2,700 BP, most variation in the PCA ordinants can be attributed to grassland taxa. The PCA results support earlier qualitative observations that the vegetation through the SR-23 profile is essentially a changing grassland with fluctuating woodland composition throughout. It also supports the conclusion of a steadily decreasing importance of arboreal forms through time.

5.2.3. Paleoenvironments of the Lower Salmon River Canyon and Columbia Plateau

The phytolith records from Hammer Creek and Lyons Bar characterize the riparian vegetation of the Lower Salmon River Canyon from Late Pleistocene to present time with a hiatus between 9,600-7,200 BP, the early Holocene (Figure 5.1).

The Lyons Bar phytolith record indicates that a stable *Picea* woodland with a mesic grass component persisted throughout the Late Pleistocene. This is the coolest period in this record. It was also a time of increased effective moisture in the Lower Salmon River increasing the suitability for spruce.

During the overlap between the Lyons Bar (SR-26) and Hammer Creek (SR-23) data, ca. 15,000-12,700 BP (Figure 5.1), the Lyons Bar record indicates a spruce woodland with a relatively stable C_3 grass cover. The presence of spruce indicates a maximum elevation depression for this species of 1,700 m. The record at Hammer Creek indicates a spruce woodland/grassland vegetation from 17,000-14,900 BP. However, after this time a Ponderosa pine woodland with a more xeric grassland developed and persisted until 12,700 BP. This vegetation change is not recorded in the Lyons Bar profile even though the two sites are separated by only 4 km.

In present day Idaho, small stands of spruce exist as low as 610 masl but they are confined to moist areas of cold valley bottoms (Uchytil 1991). This suggests cold and moist conditions at Lyons Bar but not at Hammer Creek. A combination of factors may account for the difference in local vegetation cover between the two sites from 14,900 BP to 12,700 BP. Davis (2001) suggested that higher groundwater levels and moisture retained by finer sediments may have ameliorated the effects when more xeric conditions persisted elsewhere. The local environment at Lyons Bar may have also contributed to the continuance of mesic vegetation as the site is located at the mouth of an ephemeral drainage which, even today, supports more lush, woody vegetation than seen elsewhere in the canyon.

The paleoclimate in the Lower Salmon River Canyon inferred from phytolith assemblages is compared to that established by Davis (2001) and Davis and Muehlenbachs (2001) in Table 5.2. The stable isotope record derived from river mussel shells does not correlate well with the phytolith data because the former is more a measure of river conditions and not necessarily a proxy for climatic conditions (Davis and Muehlenbachs 2001). However, there is good correlation between the paleoclimate record established in this study and that of Davis (2001) based on the independent methods of stable isotope and grain size analysis from the same sections. There is agreement in both the timing and character of trends inferred from these two different proxies. Both records capture an initial cold period which ended ca. 14,900 BP (phytolith Zone I), though Davis (2001) noted a period of fine sand deposition, which he interpreted as aridity between 16,800-15,800 BP. After this initial cool period, the phytolith record exhibits a warmer and more arid climate from 14,900-12,700 BP, suggested by a rise in C_4 grasses and the presence of drought tolerant

Table 5.2. Generalized summary of Lower Salmon River Canyon paleoclimatic data.

	River Mussel Isotopic Data (Davis and Muehlenbachs 2001)	Isotopic and Grain Size Data (Davis 2001)	Results of Phytolith Analysis	Phytolith Zone
	Modern conditions.	Sharp rise in C_{13} and low O_{18} see onset of arid conditions.	Warm and dry, modern assemblage.	VI
			Increasing Chloridoid forms to highest in profile, decreasing Pooid and Panicoids. Arid phase. Onset of dry conditions.	V
	Wettest period.			
2,000 BP	Moist conditions but gradually becoming drier.			
		All C_{13} values decrease meaning fewer C_4 plants. Decreasing O_{18}. Persistence of cool/moist conditions.		
			Pooid forms at highest levels in profile. Panicoid forms sparse and near absence of Chloridoid forms. Sparse non-grass morphotypes. Wettest period in record. Largely treeless C_3 grassland.	IV
4,000 BP	Moist conditions (rapid change).			
	Rapid shift to more arid conditions than previous.			
		Slopes and floodplains exhibit decreasing C_{13} meaning fewer C_4 plants. Return to cool/moist climatic conditions.		
6,000 BP			Pooid dominance, very low levels of C_4 forms and non-Poaceae forms suggesting largely treeless, cool/moist conditions.	III
			Sampled but no phytoliths present.	
8,000 BP	Arid.			
	Moist.			
	Arid.			
		Vegetative stability. Fluctuating O_{18} values.		
	Moist.			
10,000BP		O_{18} and C_{13} rise indicating warming and drying from previous stage. Highest rate of fine sand sedimentation. Arid conditions.		
	Arid, driest period in this record.			
	Moist.			
	Arid.			
12,000BP	No record.			
14,000BP			Increasing C_4, and *Pinus ponderosa* forms. Suggests increasing temperatures and aridity from the previous zone.	II
16,000BP		Decr. O_{18}, cold climate.		
			Abundance of Pooid forms with minor C_4 component. Non-grass cover sparse and composed primarily of *Picea* and *Pinus monticola* forms. Coldest conditions in this record.	I
18,000BP		Incr. fine sand, incr. aridity.		
20,000 BP				
		Oscillatory decline in O_{18} composition. Fluctuating C_3 vs. C_4 plant dominance. Coldest period on record.		

▒ Warm/Arid

▨ Cool/Humid

Pinus ponderosa (phytolith Zone II). Higher $\delta^{13}C$ values and $\delta^{18}O$ values during this time also indicate an increase in C_4 plants and greater aridity (Davis 2001).

Davis (2001) demonstrated sporadic floodplain development took place between 11,400-8,500 BP in the Lower Salmon River Canyon. The sterile zone in the phytolith record occurs, unfortunately, at a time of significant climate change. Glacial advances occurred 13,320-12,800 BP and again at 9,900 BP on Mt. Rainier, Washington. The lack of evidence for a Younger Dryas glacial advance has been attributed to aridity (Heine 1989). Davis (2001) notes a period of warm/arid conditions between 11,000-10,000 BP which he interprets as the Younger Dryas. The faunal assemblage from Jaguar Cave, Idaho, ca.11,580 BP, is composed of a number of cold adapted, tundra/steppe species including *Dicrostonyx torquatus* (collared lemming) and *Lagarus curtatus* (sagebrush vole) (Guilday and Adam 1967). Elias (1996) used paleoentomological data to infer paleotemperatures for the Northern Rocky Mountains and suggested that at 14,500 BP the mean July temperature was at least –10°C colder and the mean January temperature was at least –26°C colder than at present.

Several palynological studies provide a record of vegetation for the mountainous regions surrounding the Columbia Plateau (see Mack *et al.* 1976; Mack *et al.* 1978; Mack *et al.* 1979, 1983; Mehringer *et al.* 1977; Barnowsky 1985). The pollen data from this region indicate that during the Late Pleistocene-Early Holocene, the vegetation communities in the mountain ranges were predominantly steppe with *Artemisia*, grass and pine species (see Mehringer *et al.* 1977; Mack *et al.* 1978; Mack *et al.* 1979, 1983). The pollen records during the period following deglaciation, typically between 11,000-10,000 BP, indicate a warming and drying trend. Elias (1996) suggests gradual warming until 10,000 BP, when temperatures in July were at least 4°C warmer and January temperatures were at least 6°C warmer than present.

In the Lower Salmon River Canyon, Davis (2001) suggests that the warming and drying trend lasted until ca. 9,000 BP (Table 5.2) after which conditions became cooler and more moist than seen previously. The phytolith record beginning at ca. 7,200 BP provides evidence for a cool and wet climate (phytolith Zone III), becoming more so by 5,500 BP. This climate persisted until ca. 2,400 BP (phytolith Zone IV).

Davis (2001) records decreasing $\delta^{13}C$ values, indicating the presence of fewer C_4 plants and decreasing $\delta^{18}O$ values, and also suggests wetter conditions during this period. After 2,400 BP, both records demonstrate a trend towards the modern, warm/dry climate (phytolith Zones V and VI). In the phytolith record (phytolith Zones V and VI), this is manifested as increased C_4 plants, namely chloridoid forms and a general absence of woodland taxa. Davis (2001) sees this trend in a sharp rise in $\delta^{13}C$ and $\delta^{18}O$ indicating the onset of drier conditions.

Regionally, there was persistent alluviation in the Lower Salmon River Canyon from 8,500-2,000 BP, punctuated by a period of downcutting at 2,200 BP (Davis 2001). By 4,000 BP, regional pollen records suggest a cooler and moister vegetation cover (Mehringer *et al.* 1977; Mack *et al.* 1978, 1983). The paleoentomological data suggest that the beginning of this time span, ca. 9,000 BP, was slightly warmer than present by a few degrees Celsius but by 3,000 BP temperatures were within the modern range (Elias 1996).

5.3 Summary and Conclusions

The results of phytolith studies in the Lower Salmon River Canyon identified six episodes of vegetation fluctuations. They demonstrate that phytolith analysis is an effective and useful paleoenvironmental tool in areas where pollen would not preserve. It has provided for low elevation, a vegetation and climate history which is different from high elevation palynological studies. Additionally, the ability to distinguish between grass subfamilies is invaluable when studying changes in vegetation conditions in grasslands such as the Lower Salmon River Canyon.

The data from this study do not fully support Davis' (2001) 'Oasis effect' hypothesis based on the presence of stable and lush riparian environment since deglaciation. The phytolith data indicates mesic vegetation through this time span. There were significant changes, namely a vegetation change to taxa reflecting cool/moist conditions which peaked by 3,500 BP, the middle of the Neoglacial (Davis

1988). From 6,000 BP to the present, there was also a steady shift in vegetation to a more restricted woodland component.

Chapter 6: Summary

Until recently, little paleoenvironmental research has been conducted in the Lower Salmon River Canyon, or at any low elevation sites on the Columbia Plateau. To date, the majority of our knowledge for this area has come from pollen cores recovered from high elevation lakes and bogs in the surrounding Cascade and Rocky Mountain Ranges. Additionally, paleoenvironmental records older than the Pleistocene-Holocene transition are rare for the Columbia Plateau even though the area was largely ice free. Samples taken from the Hammer Creek and Lyon's Bar exposures in the Lower Salmon River Canyon have demonstrated the value of phytolith analysis for paleoenvironmental reconstruction. They offer a paleovegetation record from ca. 20,000 years ago until the present with one hiatus. This study demonstrates the usefulness and applicability of phytolith studies to low elevation grasslands with records that reach back to full glacial times.

Modern phytolith assemblages have been shown to be representative of modern plant communities indicating that fossil assemblages can represent past plant communities. Phytoliths are preserved in conditions where other proxies may not be. As well, phytolith analysis can distinguish grasses identified to the subfamily level. This is of great use for detecting vegetation changes in regions where grassland environments have persisted for long periods of time. In the study area, grasslands have existed for tens of thousands of years.

This is the second paleoenvironmental study done in the canyons of the Lower Salmon River, following Davis' (2001) study of sediment stable isotopes and grain size. Both studies show a set of environmental conditions in the riparian environment unique from the character of environmental changes from high elevation montane records. Results indicate that riparian paleovegetation communities were quite stable during the glacial period and somewhat less so during the initial stages of deglaciation. Between 9,000-2,000 BP, the phytolith record indicates a mesic grassland environment. This may have made the canyon bottom a preferred location for human settlement when compared to upland areas.

The phytolith record indicates that a predominantly C_3 grassland was present ca. 20,000 BP, the end of the last glacial period. Phytolith frequencies indicate non-grass species were predominantly spruce, unspecified dicotyledon forms and perhaps *Pinus monticola*. There was remarkably little change for thousands of years, from this time until deglaciation began.

At the end of the glacial period the climate became warmer and more arid than during earlier times. This trend persisted through the Early Holocene period. A C_3 grassland continued to predominate in the Lower Salmon River Canyon but C_4 grasses became more abundant than during the Late Pliestocene. There was also a change in the arboreal species composition, particularly an increase in *Picea/Pinus ponderosa* cover. This may have been due a combination of higher temperatures than seen previously and more available moisture than the present time. Davis (2001) suggested that an elevated groundwater table and/or the presence of river water provided sufficient moisture for the vegetative community.

It was during the Pleistocene/Holocene transition that the first evidence of human occupation has been found on the Columbia Plateau and the Lower Salmon River Canyon. Early settlement sites are sparse across the landscape and have low artifact densities suggesting a period of short-term site habitation and a great degree of mobility. This was likely an adaptation to the exploitation of wandering herds of large animals.

Unfortunately, the Pleistocene-Holocene transition period is largely absent in the phytolith record due to the lack of significant quantities of phytoliths in sediments of this period.

The phytolith record picks up again during the Middle Holocene, ca. 7,200 BP. Grasslands continued to predominate but there was a noticeable decline in C_4 grass morphotypes along with a scarcity of non-grass phytoliths. This period was cooler than the Early Holocene climate. Cultural development shows this to be a period of extensive seasonal hunting and gathering. The archaeological record displays more frequent and intensively used sites suggesting that population density was increasing and that there was intensification of resource utilization, especially in and around river canyons.

The archaeological record indicates that the processing of plant material intensified during the Middle Holocene. The phytolith record suggests that root crops (Agavaceae/Alliaceae forms) may have been available the entire time covered by these profiles. But the relationship of diagnostic morphotypes for these families needs further exploration.

Phytolith morphotype frequencies between 5,200 BP and 2,500 BP indicate an intensification of the cool/moist conditions initiated in the previous phase. This is the onset of Neoglacial conditions. A largely mesic, treeless grassland predominated through this period. It was during this time that house pit structures appeared along Columbia Plateau rivers. There was development of storage techniques, intensified house pit occupations and use of root crops. There was also evidence for semi-sedentary villages by the end of this period.

A warming and drying trend characterized the climate of the Late Holocene. Archaeological evidence indicates year-round occupation on and intensified utilization of canyon areas with seasonal use of upland areas for resource procurement and processing. This may have been a response to relatively amiable canyon conditions.

Since ca. 20,000 BP, there has been a trend of decreasing tree cover in the Lower Salmon River. PCA has suggested a grassland with a primarily spruce non-grass component early on. As time progressed, fewer woody species appeared in the record.

While many questions have been answered in this study, others have arisen. It is important that further research be conducted to investigate paleoenvironmental conditions in the Lower Salmon River Canyon. One possible avenue for further research would be the correlation of climatic conditions with a suite of modern phytolith 'rain' spectra in the Columbia Plateau. This would also allow regression formulations which have been shown to be useful in quantifying paleoenvironmental changes (such as Fredlund and Tieszen 1997; Fredlund *et al.* 1998).

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Appendix A: Phytolith Scanning Sheet

Phytolith Scanning Sheet			
Site			Slide#
Corresponding Provenience Information			
Total Count			
Apiaceae			
Lomatium forms			
Polylobate with cupped bottom (30IIIC)			

Asteraceae		
spp.		
Multicell. hairs (40IIIBa200, 40IIIBa300)		
Hair base (40IVBa1) (40IVG)		
Blackened, perforated epiderm. (20IB)		

Cyperaceae		
spp.		
Single peaked hat (30XA)		
Multipeaked hats (30XB)		

Agavaceae		
spp.		
Bipointed cooling tower (30IF)		
Top sq/btm sm. rnd flt/sloped sides (30IICb1)		
Cooling tower		

Agavaceae/Alliaceae		
spp.		
Deep profile bilobate		
Decorated bilobate		
Polylobate/oval bottom		
Bilobate with cupped bottom		

Pinaceae		
Pseudotsuga menziesii		
Asteroclerieids		
Pinus ponderosa		
Spiny irreg. bodies/oval shape		
Irreg. elong. pitted plates w/ projections		
Irreg. rod with projections on all sides		
Picea and *Pinus monticola*		
Blocky, smooth polyhedron		
Pitted, blocky polyhedron		
Picea and *Pinus ponderosa*		
Blocky polyhedron, grainy surface		
Larix occidentalis		
Epidermal cells		

Polypodiaceae		
Pteridum		
Anticlin.epid. with C-shape margins		

Rosaceae		
Rosa woodsii		
Mesophyll (25)		

Ulmaceae		
spp.		
Hair base (40IVBA4)		
Celtis reticulata		
Epiderm quads w/ projections (21IID)		
Sphere with branched tent (80IJ)		
Armed trichome (40IIAa)		
Hair w/ triang. round base (40 IIIAb200Bb)		

Dicot Forms		
spp.		
Anticlinal epidermis (20Iaa, 20Iab)		
Tracheid		
Sclerid		

Other		
Diatoms		
Sponge spicules		

Poaceae Counts			
Site			Slide#
Corresponding Provenience Information			
Total Count			

Chloridoid forms (C4 plants, xeric)		
spp.		
Saddle shapes/chloridoid type		
Other chloridoid types		

Panicoid forms (C4 plants, mesic)		
spp.		
Lobate		
Panicoid type		
Cross shapes		
Other panicoid forms		

Pooid forms (C3 plants, cooler)		
spp.		
Keeled		
Conical/rondel		
Pyramidal		
Crenate		
Stipa type		
Other pooid forms		

Other Poaceae forms		
spp.		
Dble outline trichomes/hairs (cyper. + poa.)		
Epidermal quads w/ diagonal etching		
Epid. quads. with branching/thin projections		
Armed circular hair bases		
Epid. quads with upward teeth		
Single outline trichomes armed only on base		
Bulliform cells		

Appendix B: Statistical Tests Applied to Data Recovered from the Hammer Creek and Lyons Bar Profiles

B.1. Constrained Single Link Method for Determining Phytolith Zones

The following description of this statistical method relies heavily on Birks and Gordon (1985) and Grimm (1988). A full description of Constrained Single Link Method (CSLM) will be given for Hammer Creek. Because the methods used at Lyons Bar are the same, only a summary of CSLM results will be shown for this exposure.

The first step in the CLSM for determining phytolith zonation is to calculate measurements of dissimilarity between stratigraphically adjacent levels.

B.1.1. Creating a Dissimilarity Matrix

A measure of dissimilarity (*d*) of two phytolith strata (*a* and *b*) is an indicator of the differences in the percentages of phytolith types. In this calculation, $p_{i1}, p_{i2} \ldots p_{in}$ are the percentages of the *i*th strata belonging to each of the phytolith types (t) used in this calculation.

The measure of dissimilarity calculated here is called the 'city block' or 'Manhattan' metric. The measure of dissimilarity can be calculated using the following formula:

$$d(a, b) = \sum_{k-1}^{t} |p_{ik} - p_{jk}|$$

The dissimilarity between strata *a* and *b* is defined as the sum of the absolute differences between their proportions of each phytolith type.

It is assumed that difference between two strata (say *a* and *b*) can be represented stratigraphically. Conditions (i), (ii) and (iii) apply when calculating the measure of dissimilarity (*d*). The larger the integer $d(a, b)$, the less similar strata *a* and *b* are. (Birks and Gordon 1985):

i. $d(a, b) \geq 0$
ii. $d(a, a) = 0$

iii. $d(a, b) = d(b, a)$

This method of calculating data may lead to some distortion, but does preserve the major features of the data set. In fact, as the three grass short cell phytolith classifications are the most ecologically abundant taxa, they will be the major influences in zone placement. On the other hand, the other groupings of phytolith types will play a less prominent role in zone placement.

The raw counts and percentages of phytolith types used for this calculation are shown in Table B.1 and Table B.2. Since one of the minimum conditions (iii) is $d(a,b) = d(b,a)$, only one side of the diagonal need be calculated (Table B.3. and Table B.4.).

B.1.2. Sample calculation of the measure of dissimilarity

A sample calculation is shown using SR-23-00 and SR-23-01 (henceforth called *00* and *01*).

$$d(00, 01) = \sum_{k-1}^{t} |p_{ik}-p_{jk}|$$

$$d(00, 01) = |1.19-0.39| + |0.79-0.39| + |1.98-0.00| + |3.56-4.33| + \ldots + |5.93-4.72| + |4.35-3.15| + |69.17-77.56| + |6.69-6.72|$$

$$d(00, 01) = 0.80 + 0.40 + 1.98 + 0.77 + \ldots + 1.21 + 1.20 + 8.39 + 0.03$$

$$d(00, 01) = 18.36$$

B.1.3. The Constrained Single Link Method: Hammer Creek

This method of delineating strata is derived from the single link method of cluster analysis with the added constraint that classes must comprise sets of stratigraphically neighbouring strata at all times (Birks and Gordon 1985). It uses an agglomerative algorithm which was applied to the Hammer Creek data.

In order to lessen clutter, and since we will be looking at dissimilarity between neighbouring strata, only the diagonal numbers across the matrix need be used. There

Sample	Cyperaceae	Agavaceae	Agavaceae/Alliaceae	Pinaceae	Polypodiaceae	Ulmaceae	Dicot Forms	Other	Chloridoid	Panicoid	Pooid	Other Poaceae
sr-23-0	3	2	5	9	0	1	6	9	15	11	175	17
sr-23-1	1	1	0	11	0	0	3	4	12	8	197	17
sr-23-2	4	2	1	12	0	2	1	2	14	3	203	21
sr-23-3	2	5	3	10	0	0	0	8	10	9	167	10
sr-23-4	0	3	5	7	0	0	3	9	2	15	180	16
sr-23-5	1	0	1	2	0	0	4	3	2	15	234	8
sr-23-6	0	2	1	8	0	0	0	10	2	18	197	6
sr-23-7	2	6	3	7	0	0	1	5	2	11	213	6
sr-23-8	1	0	0	9	0	1	2	4	0	14	185	11
sr-23-9	1	2	1	7	0	0	0	6	2	5	220	4
sr-23-10	0	1	0	19	1	0	5	10	1	4	185	5
sr-23-11	0	1	0	23	0	2	2	14	1	4	176	12
x												
sr-23-13	0	2	1	16	0	1	2	14	2	6	187	12
x												
sr-23-19	0	0	1	23	0	0	2	4	2	18	168	12
sr-23-20	0	1	5	10	0	0	3	9	0	19	182	13
sr-23-21	3	6	1	19	0	0	4	4	3	16	179	5
sr-23-22	1	2	4	27	0	0	1	4	5	17	158	6
sr-23-23	0	6	4	24	0	0	3	4	5	17	166	5
sr-23-24	1	2	3	25	0	0	1	2	3	14	160	11
sr-23-25	1	5	2	27	0	0	0	5	5	20	156	7
sr-23-26	0	5	5	37	0	2	5	5	7	22	146	12
sr-23-27	3	2	0	18	0	0	3	4	9	24	176	11
sr-23-28	0	1	3	43	0	6	6	2	2	15	135	8
sr-23-29	0	6	2	35	0	0	2	3	5	15	182	13
sr-23-30	2	3	0	12	0	3	2	5	6	8	181	14
sr-23-31	1	3	3	18	0	1	2	2	2	10	178	2
sr-23-32	0	1	2	15	0	0	5	9	2	18	171	8
sr-23-33	1	2	1	2	0	0	8	19	1	21	179	11
sr-23-34	1	0	2	23	0	4	8	5	6	13	166	3
sr-23-35	1	1	1	13	0	0	8	17	3	10	181	6
sr-23-36	3	2	0	13	0	1	3	16	4	6	180	6
sr-23-37	0	4	1	12	0	3	4	22	1	14	169	14
sr-23-38	0	1	3	9	0	0	3	16	1	8	202	2
sr-23-39	0	2	2	10	0	0	7	12	2	13	189	3
sr-23-40	0	2	4	13	0	1	7	21	1	9	198	9

Table B.1. Raw counts of phytolith family/subfamily representation of the SR-23 data.

	Cyper	Agava	Aga/Allia	Polyp	C.retic	Dicot	Chlorid	Panic	Pooid	Poac	Pseudot	P.Pond	Pic/Pmnt	Pic/Ppon
sr-23-0	1.19%	0.79%	1.98%	0.00%	0.40%	2.37%	5.93%	4.35%	69.17%	6.72%	0.00%	0.79%	0.40%	2.37%
sr-23-1	0.39%	0.39%	0.00%	0.00%	0.00%	1.18%	4.72%	3.15%	77.56%	6.69%	0.00%	1.97%	0.79%	1.57%
sr-23-2	1.51%	0.75%	0.38%	0.00%	0.75%	0.38%	5.28%	1.13%	76.60%	7.92%	0.00%	0.75%	1.51%	2.26%
sr-23-3	0.89%	2.23%	1.34%	0.00%	0.00%	0.00%	4.46%	4.02%	74.55%	4.46%	0.00%	0.45%	0.89%	3.13%
sr-23-4	0.00%	1.25%	2.08%	0.00%	0.00%	1.25%	0.83%	6.25%	75.00%	6.67%	0.00%	0.00%	1.25%	1.67%
sr-23-5	0.37%	0.00%	0.37%	0.00%	0.00%	1.48%	0.74%	5.56%	86.67%	2.96%	0.00%	0.37%	0.37%	0.00%
sr-23-6	0.00%	0.82%	0.41%	0.00%	0.00%	0.00%	0.82%	7.38%	80.74%	2.46%	0.00%	0.00%	0.82%	2.46%
sr-23-7	0.78%	2.34%	1.17%	0.00%	0.00%	0.39%	0.78%	4.30%	83.20%	2.34%	0.00%	0.00%	0.00%	2.73%
sr-23-8	0.44%	0.00%	0.00%	0.00%	0.44%	0.88%	0.00%	6.17%	81.50%	4.85%	0.00%	0.88%	0.88%	2.20%
sr-23-9	0.40%	0.81%	0.40%	0.00%	0.00%	0.00%	0.81%	2.02%	88.71%	1.61%	0.00%	0.00%	0.40%	2.42%
sr-23-10	0.00%	0.43%	0.00%	0.43%	0.00%	2.16%	0.43%	1.73%	80.09%	2.16%	0.00%	0.00%	3.03%	5.19%
sr-23-11	0.00%	0.43%	0.00%	0.00%	0.85%	0.85%	0.43%	1.70%	74.89%	5.11%	0.00%	0.00%	3.40%	6.38%
sr-23-12														
sr-23-13	0.00%	0.82%	0.41%	0.00%	0.41%	0.82%	0.82%	2.47%	76.95%	4.94%	0.00%	0.41%	2.06%	4.12%
sr-23-14														
sr-23-15														
sr-23-16														
sr-23-17														
sr-23-18														
sr-23-19	0.00%	0.43%	0.00%	0.00%	0.00%	0.87%	0.87%	7.83%	73.04%	5.22%	0.43%	3.04%	2.61%	4.35%
sr-23-20	0.00%	0.41%	2.07%	0.00%	0.00%	1.24%	0.00%	7.85%	75.21%	5.37%	0.00%	1.65%	0.00%	2.48%
sr-23-21	1.25%	2.50%	0.42%	0.00%	0.00%	1.67%	1.25%	6.67%	74.58%	2.08%	0.00%	2.50%	1.25%	4.17%
sr-23-22	0.44%	0.89%	1.78%	0.00%	0.00%	0.44%	2.22%	4.56%	70.22%	2.67%	0.00%	3.11%	1.78%	7.11%
sr-23-23	0.00%	2.56%	1.71%	0.00%	0.00%	1.28%	2.14%	7.26%	70.94%	2.14%	0.00%	2.99%	1.28%	5.98%
sr-23-24	0.45%	0.90%	1.35%	0.00%	0.00%	0.45%	1.35%	6.31%	72.07%	4.95%	0.00%	4.05%	2.25%	4.95%
sr-23-25	0.44%	2.19%	0.88%	0.00%	0.00%	0.00%	2.19%	8.77%	68.42%	3.07%	0.00%	3.51%	1.32%	7.02%
sr-23-26	0.00%	2.03%	2.03%	0.00%	0.81%	2.03%	2.85%	8.94%	59.35%	4.88%	0.00%	6.91%	0.81%	7.32%
sr-23-27	1.20%	0.80%	0.00%	0.00%	0.00%	1.20%	3.60%	9.60%	70.40%	4.40%	0.00%	3.60%	0.00%	3.60%
sr-23-28	0.00%	0.45%	1.36%	0.00%	2.71%	2.71%	0.90%	6.79%	61.09%	3.62%	0.00%	8.60%	4.98%	5.88%
sr-23-29	0.00%	2.28%	0.76%	0.00%	0.00%	0.76%	1.90%	5.70%	69.20%	4.94%	0.00%	4.94%	0.76%	7.60%
sr-23-30	0.85%	1.27%	0.00%	0.00%	1.27%	0.85%	2.54%	3.39%	76.69%	5.93%	0.00%	0.42%	2.54%	2.12%
sr-23-31	0.45%	1.35%	1.35%	0.00%	0.45%	0.90%	0.90%	4.50%	80.18%	0.90%	0.00%	2.25%	1.80%	4.05%
sr-23-32	0.00%	0.43%	0.87%	0.00%	0.00%	2.16%	0.87%	7.79%	74.03%	3.46%	0.00%	1.73%	1.73%	3.03%
sr-23-33	0.41%	0.82%	0.41%	0.00%	0.00%	3.27%	0.41%	8.57%	73.06%	4.49%	0.00%	0.82%	0.00%	0.00%
sr-23-34	0.43%	0.00%	0.87%	0.00%	1.73%	3.46%	2.60%	5.63%	71.86%	1.30%	0.00%	3.03%	2.60%	4.33%
sr-23-35	0.41%	0.41%	0.41%	0.00%	0.00%	3.32%	1.24%	4.15%	75.10%	2.49%	0.00%	2.07%	0.41%	2.90%
sr-23-36	1.28%	0.85%	0.00%	0.00%	0.43%	1.28%	1.71%	2.56%	76.92%	2.56%	0.00%	0.43%	3.42%	1.71%
sr-23-37	0.00%	1.64%	0.41%	0.00%	1.23%	1.64%	0.41%	5.74%	69.26%	5.74%	0.00%	0.82%	2.05%	2.05%
sr-23-38	0.00%	0.83%	0.83%	0.00%	0.00%	2.92%	0.83%	5.42%	78.75%	1.25%	0.00%	0.00%	1.67%	2.50%
sr-23-39	0.00%	0.41%	1.22%	0.00%	0.00%	1.22%	0.41%	3.27%	82.45%	0.82%	0.00%	0.00%	1.63%	2.04%
sr-23-40	0.00%	0.75%	1.51%	0.00%	0.38%	2.64%	0.38%	3.40%	74.72%	3.40%	0.00%	0.00%	1.13%	3.77%

Table B.2. Percentages of phytoltih family/subfamily representation.

	sr-230	sr-231	sr-232	sr-233	sr-234	sr-235	sr-236	sr-237	sr-238	sr-239	sr-2310	sr-2311
sr-23-0	na											
sr-23-1	18.36%	na										
sr-23-2	20.58%	9.20%	na									
sr-23-3	15.50%	13.36%	17.19%	na								
sr-23-4	16.98%	16.56%	21.53%	14.10%	na							
sr-23-5	37.44%	24.36%	32.27%	30.26%	24.54%	na						
sr-23-6	30.35%	21.53%	28.06%	20.13%	15.15%	16.57%	na					
sr-23-7	31.20%	21.36%	27.89%	18.86%	20.16%	12.86%	11.85%	na				
sr-23-8	29.20%	15.26%	22.88%	21.60%	16.84%	13.76%	11.19%	13.06%	na			
sr-23-9	39.14%	25.64%	29.89%	28.30%	28.22%	12.74%	16.75%	12.18%	19.78%	na		
sr-23-10	33.61%	21.27%	26.82%	25.31%	24.65%	24.51%	15.56%	20.15%	18.83%	20.93%	na	
sr-23-11	29.61%	21.45%	22.86%	20.79%	19.85%	34.65%	25.44%	30.27%	23.11%	31.41%	13.96%	na

Table B.3. SR-23 dissimilarity matrix for samples 01-11.

	sr-2319	sr-2320	sr-2321	sr-2322	sr-2323	sr-2324	sr-2325	sr-2326	sr-2327	sr-2328	sr-2329	sr-2330	sr-2331	sr-2332	sr-2333	sr-2334	sr-2335	sr-2336	sr-2337	sr-2338	sr-2339	sr-2340
sr-23-19	na																					
sr-23-20	13.52%	na																				
sr-23-21	12.91%	17.61%	na																			
sr-23-22	15.14%	25.02%	17.23%	na																		
sr-23-23	11.56%	20.92%	10.55%	8.86%	na																	
sr-23-24	8.03%	18.85%	14.50%	8.83%	10.79%	na																
sr-23-25	15.27%	26.09%	17.88%	9.65%	9.99%	12.92%	na															
sr-23-26	28.05%	36.15%	33.88%	25.61%	24.23%	26.48%	19.66%	na														
sr-23-27	12.80%	20.02%	15.21%	16.70%	14.52%	15.47%	15.01%	27.31%	na													
sr-23-28	30.85%	40.91%	35.80%	28.25%	29.65%	27.32%	28.14%	17.48%	35.69%	na												
sr-23-29	13.91%	25.91%	18.50%	9.87%	11.71%	9.06%	9.94%	20.32%	17.79%	25.00%	na											
sr-23-30	18.75%	17.03%	17.96%	22.73%	24.95%	20.90%	28.02%	39.58%	20.17%	44.88%	24.62%	na										
sr-23-31	20.75%	23.39%	14.36%	19.69%	20.29%	18.92%	27.18%	42.56%	26.09%	40.88%	25.22%	18.22%	na									
sr-23-32	10.62%	8.70%	11.35%	20.34%	16.02%	16.29%	19.73%	33.35%	15.52%	33.87%	22.37%	19.53%	20.21%	na								
sr-23-33	20.76%	16.02%	23.99%	31.94%	28.44%	25.83%	29.77%	42.15%	22.80%	45.61%	32.51%	27.27%	33.75%	15.14%	na							
sr-23-34	15.54%	25.62%	15.71%	13.44%	12.34%	14.49%	18.07%	30.83%	19.28%	29.81%	18.69%	22.31%	20.35%	17.32%	27.48%	na						
sr-23-35	22.05%	16.67%	15.96%	23.09%	24.63%	24.12%	29.74%	44.96%	25.39%	43.06%	29.58%	17.78%	21.02%	12.35%	15.03%	19.49%	na					
sr-23-36	24.73%	20.33%	17.84%	24.75%	28.49%	26.48%	31.40%	47.32%	24.81%	48.52%	31.30%	12.58%	19.24%	17.61%	22.49%	25.41%	8.52%	na				
sr-23-37	22.83%	19.45%	24.48%	26.33%	24.99%	24.12%	26.40%	36.34%	23.35%	39.18%	21.76%	21.62%	32.00%	19.67%	17.33%	26.09%	18.50%	21.78%	na			
sr-23-38	24.50%	15.58%	18.33%	27.18%	25.48%	26.49%	32.11%	46.51%	28.66%	44.69%	31.27%	19.73%	14.77%	13.96%	19.80%	21.12%	11.49%	14.31%	23.23%	na		
sr-23-39	31.54%	20.92%	27.07%	32.52%	32.66%	33.55%	39.85%	55.19%	36.44%	53.97%	39.11%	23.51%	16.43%	22.80%	26.12%	31.44%	16.29%	14.91%	28.01%	11.24%	na	
sr-23-40	23.67%	14.95%	20.30%	24.89%	25.97%	24.78%	32.00%	43.72%	27.93%	42.18%	30.60%	18.20%	22.82%	13.05%	14.79%	24.21%	7.16%	11.24%	15.12%	13.73%	15.53%	na

Table B.4. SR-23 dissimilarity matrix for samples 19-40.

is a section with 'no data' in the profile, which violates the requirement that neighbouring strata be used. To correct for this, the Hammer Creek data set was calculated in two steps, once for the data before the 'no data' block and once for the data after.

B.1.4 Application of the agglomerative algorithm for SR-23-00 through SR-23-11

Data from the dissimilarity matrix Table B.3 can be shown as:

00 01 02 03 04 05 06 07 08 09 10 11
18.36 9.20 17.19 14.10 24.54 16.57 11.85 13.06 19.78 20.93 13.96

Initially, there are eleven individual groups, each with a dissimilarity value shared with adjacent strata. In this representation, the bottom line shows the measure of dissimilarity for those above bracketing sample designations. For example, the measure of dissimilarity between samples 01 and 02 is 9.20. This is the smallest value of dissimilarity of all, indicating these strata are the most similar. So, the first agglomeration is between levels A1 and A2 at a height of 9.20.

There is now a need to indicate the dissimilarity between the grouped levels (01,02) and the stratigraphically neighbouring levels of 00 and 03. In the CSLM, the measure of dissimilarity between the grouped data and the next strata is defined by the smaller of the dissimilarities between 02 and 03 (17.19) and 01 and 03 (13.36) (see uncondensed dissimilarity matrix Table B.3). Similarly, a comparison is done for the relationship between 01 and 00 (18.36) and 02 and 00 (20.58). None of the other measures are affected by this agglomeration. So, after the first agglomeration the dissimilarity matrix may be represented like this:

00 (01,02) 03 04 05 06 07 08 09 10 11
18.36 13.36 14.10 24.54 16.57 11.85 13.06 19.78 20.93 13.96

We now have ten individual groups, each with a dissimilarity value shared with adjacent groups. The process continues with the second agglomeration. The next lowest measure of dissimilarity is now between 06 and 07 making the (06,07) group at a height of 11.85. The dissimilarity matrix is restructured as before. The dissimilarity between 06 and 08 are compared (11.19) as are 07 and 08 (13.06) with the smaller measure then becoming the dissimilarity between the newly agglomerated (06,07) data and the higher strata 08. The lower strata are similarly compared. The measure of dissimilarity of 06 with 05 (16.57) and 07 with 05 (12.86) are compared with the lower number (12.86) becoming the new dissimilarity measure between the grouped strata (06,07) and 05. The second amalgamation leaves the dissimilarity matrix as follows:

00		(01,02)		03		04		05		(06,07)		08		09		10		11
	18.36		13.36		14.10		24.54		12.86		11.19		19.78		20.93		13.96	

The third agglomeration step results in 08 becoming part of (06,07) to create (06-08) at a height of 11.19. It should be noted that after the second amalgamation, stratum 06 was merged with stratum 08, as the dissimilarity between 07 and 08 prevented earlier amalgamation because of stratigraphical constraints. In other words, 06 and 08 were more similar than 07 and 08, but because dissimilarity measures must be from adjacent groups, 06 and 08 could not agglomerate until 06 and 07 had been. Because of this, the height of this amalgamation is not 11.19 as previously mentioned but is actually 11.85 (the height at which 06 and 07 joined).

Subsequent calculations of the dissimilarity measures for the matrix compare strata 06 (16.75), 07 (12.18) and 08 (19.78) with 09. Likewise the 06 (16.57), 07 (12.86) and 08 (13.76) dissimilarity measures are compared with 05. Again, the lowest measures are used to develop the dissimilarity matrix as follows:

00		(01,02)		03		04		05		(06-08)		09		10		11
	18.36		13.36		14.10		24.54		12.86		12.18		20.93		13.96	

Subsequent steps are summarized as follows:

00 (01,02) 03 04 (05-09) 10 11
18.36 13.36 14.10 15.15 15.56 13.96

—

00 (01,02) 03 04 (05-09) 10 11
18.36 13.36 14.10 15.15 15.56 13.96

—

00 (01-03) 04 (05-09) 10 11
15.50 14.10 15.15 15.56 13.96

—

Two adjacent groups are created in this last merge. Next, measures of dissimilarity from 05 through 09 with 04 as well as 05 through 09 with 10 are compared. The smallest quantity (15.56) becomes the new dissimilarity measure.

00 (01-03) 04 (05-09) (10,11)
15.50 14.10 15.15 15.56

Subsequent agglomerations are as follows.

—

00 (01-04) (05-09) (10,11)
15.50 15.15 15.56

—

00 (01-09) (10,11)
15.50 15.56

—

(00-09) (10,11)
15.56

B.1.5. Application of agglomerative algorithm for SR-23-19 through SR-23-40

The Constrained Single Link Method was then applied to the data set following the 'no data' block. The dissimilarity matrix for this data set is summarized as follows:

19 20 21 22 23 24 25 26 27 28 29 30

13.52 17.61 17.23 8.86 10.79 12.92 19.66 27.31 35.69 25.00 24.62
18.22

31 32 33 34 35 36 37 38 39 40
20.21 15.14 27.48 19.49 8.52 21.78 23.23 11.24 15.53

The first merge is between 35 and 36. The calculation of new dissimilarity measures and the subsequent agglomerative steps continue as described above. The following is a summary of the calculations.

19 20 21 22 23 24 25 26 27 28 29 30

13.52 17.61 17.23 8.86 10.79 12.92 19.66 27.31 35.69 25.00 24.62
18.22

31 32 33 34 (35,36) 37 38 39 40
20.21 15.14 27.48 19.49 18.50 23.23 11.24 15.53

19	20	21	(22,23)	24	25	26	27	28	29	30
13.52	17.61	10.55	8.83	12.92	19.66	27.31	35.69	25.00	24.62	18.22

31	32	33	34	(35,36)	37	38	39	40
20.21	15.14	27.48	19.49	18.50	23.23	11.24	15.53	

—

19	20	21	(22-24)	25	26	27	28	29	30
13.52	17.61	10.55	9.65	19.66	27.31	35.69	25.00	24.62	18.22

31	32	33	34	(35,36)	37	38	39	40
20.21	15.14	27.48	19.49	18.50	23.23	11.24	15.53	

—

19	20	21	(22-25)	26	27	28	29	30
13.52	17.61	10.55	19.66	27.31	35.69	25.00	24.62	18.22

31	32	33	34	(35,36)	37	38	39	40
20.21	15.14	27.48	19.49	18.50	23.23	11.24	15.53	

—

19	20	(21-25)	26	27	28	29	30
13.52	17.61	19.66	27.31	35.69	25.00	24.62	18.22

31	32	33	34	(35,36)	37	38	39	40
20.21	15.14	27.48	19.49	18.50	23.23	11.24	15.53	

—

19	20	(21-25)	26	27	28	29	30
13.52	17.61	19.66	27.31	35.69	25.00	24.62	18.22

31	32	33	34	(35,36)	37	(38,39)	40
20.21	15.14	27.48	19.49	18.50	23.23	13.73	

—

(19,20) (21-25) 26 27 28 29 30
8.03 19.66 27.31 35.69 25.00 24.62 18.22

31 32 33 34 (35,36) 37 (38,39) 40
20.21 15.14 27.48 19.49 18.50 23.23 13.73

—

(19-25) 26 27 28 29 30
19.66 27.31 35.69 25.00 24.62 18.22

31 32 33 34 (35,36) 37 (38,39) 40
20.21 15.14 27.48 19.49 18.50 23.23 13.73

—

(19-25) 26 27 28 29 30
19.66 27.31 35.69 25.00 24.62 18.22

31 32 33 34 (35,36) (37-40)
20.21 15.14 27.48 19.49 7.16

—

(19-25) 26 27 28 29 30 31 (32-34) (35-40)
19.66 27.31 35.69 25.00 24.62 18.22 20.21 12.35

—

(19-25) 26 27 28 29 30 31 (32-40)
19.66 27.31 35.69 25.00 24.62 18.22 14.77

—

(19-25) 26 27 28 29 30 (31-40)
19.66 27.31 35.69 25.00 24.62 12.58

—

(19-25) 26 27 28 29 (30-40)
19.66 27.31 35.69 25.00 18.69

—

(19-25) 26 27 28 (29-40)
19.66 27.31 35.69 25.00

—

(19-26) 27 28 (29-40)
14.52 35.69 25.00

—

(19-27) 28 (29-40)
17.48 25.00

—

(19-28) (29-40)
8.70

Using CLSM, as detailed above, phytolith zones have been defined. The data is presented in summary Tables B.5 and B.6. Secondly, using the height of agglomeration, a graphical representation of zone definition is given in Figure B.1. Thirdly, the delineated zones are imposed on the Hammer Creek phytolith profile to visualize all possible zonation delineations (Figure B.2).

The clarified zones are imposed over the Hammer Creek profile as they will be used in this study. Finally a 'cut' is made at a height of ~15 to the earlier portion of the profile and at ~19 in the later to define the phytolith zones shown in Figure B.2.

Table B.5. Summary of agglomeration heights using the CSLM of phytolith zonation for SR-23-00 through SR-23-11.

Agglomeration Stage	Grouping	Height
1	01, 02	9.20
2	06, 07	11.85
3	(06,07), 08	11.85
4	(06-08), 09	12.18
5	(06-09), 05	12.74
6	(01,02), 03	13.36
7	10, 11	13.96
8	(01-03), 04	14.10
9	(01-04), (05-09)	15.15
10	00, (01-09)	15.50

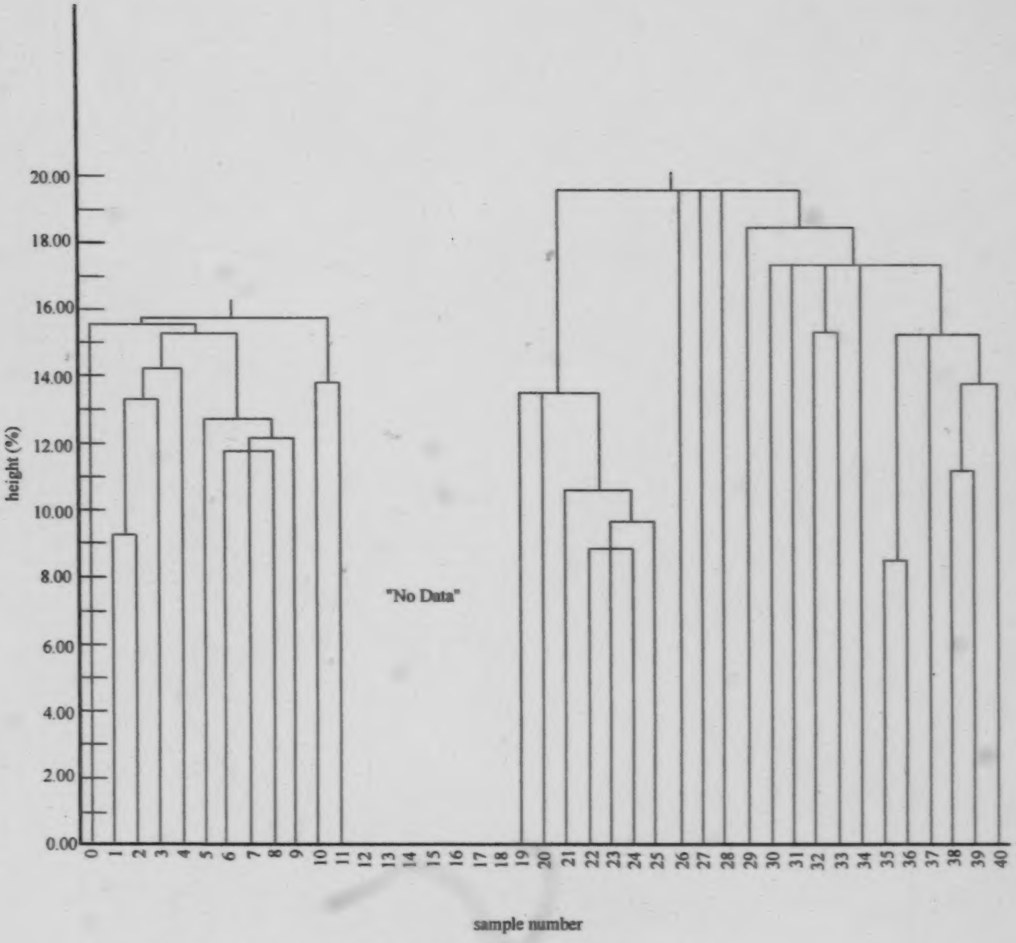

Figure B.1. Constrained Single Link Method dendrogram.

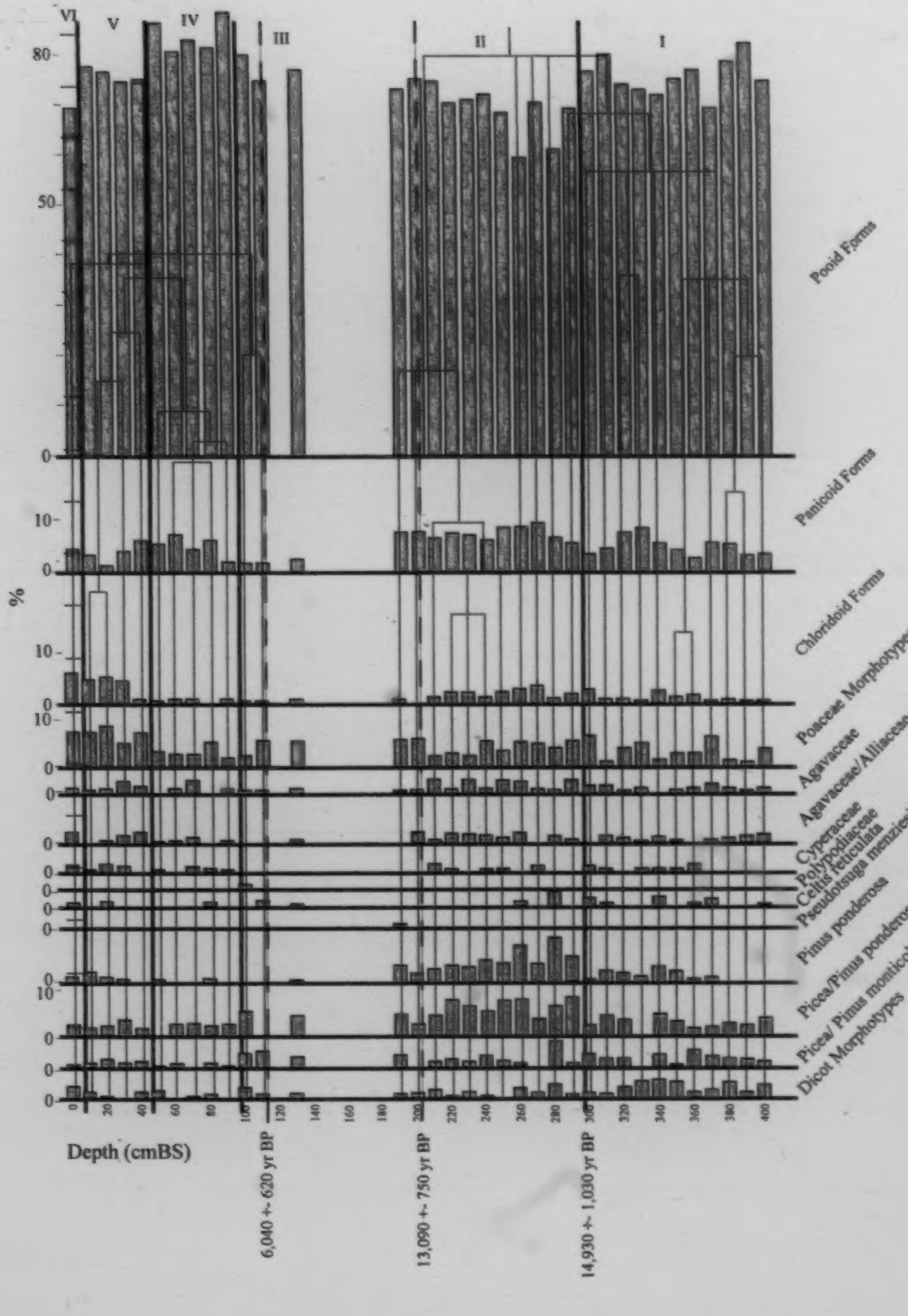

Figure B.2. CSLM dendrogram and the phytolith profile.

Table B.6. Summary of agglomeration heights using the CSLM of phytolith zonation for SR-23-19 through SR-23-40.

Agglomeration Stage	Grouping	Height
1	35, 36	8.52
2	22, 23	8.86
3	(22,23), 24	8.86
4	(22-24), 25	9.65
5	21, (22-25)	10.55
6	38, 39	11.24
7	19, 20	13.52
8	(19,20), (21-25)	13.52
9	(38,39), 40	13.73
10	37, (38-40)	15.12
11	(35,36), (38-40)	15.12
12	32, 33	15.14
13	(32,33), 34	17.32
14	(32-34), (35-40)	17.32
15	31, (32-40)	17.32
16	30, (31-40)	17.32
17	29, (31-40)	18.69
18	(19-25), 26	19.66
19	(19-26), 27	19.66
20	(19-27), 28	19.66

B.1.6. The Constrained Single Link Method: Lyons Bar

This method of delineating strata was calculated for the samples at Lyons Bar. The method was the same as that described in detail in the above sections. SR-26A and SR-26C are not stratigraphically neighboring profiles and hence were dealt with separately.

The SR-26 raw data, percentages and dissimilarity matrix are shown in Table B.7., Table B.8. and Table B.9. Using the CLSM as detailed above, no phytolith zones could be confidently defined. The data is presented in summary Tables B.10 and B.11. Secondly, using the height of agglomeration, a graphical representation of the zone formation is given in Figure B.3. Thirdly, the delineated zones are superimposed on the Lyon's Bar profile in order to visualize possible zonation delineation for phytolith

Sample	Cyperaceae	Agavaceae	Agavaceae/Alliaceae	Pinaceae	Polypodiaceae	Ulmaceae	Dicot Forms	Other	Chloridoid	Panicoid	Pooid	Other Poaceae
sr-26-a1	1	3	2	14	0	0	13	27	8	19	156	4
sr-26-a2	0	1	1	15	0	0	14	26	8	18	153	4
sr-26-a3	0	1	2	18	0	0	15	32	13	21	141	10
sr-26-a4	2	1	0	20	0	0	11	26	5	18	174	3
sr-26-a5	1	1	0	13	0	0	11	21	5	14	172	2
sr-26-a6	1	0	1	19	0	0	14	23	7	18	179	7
sr-26-a7	1	4	2	10	0	0	13	27	10	23	170	5
sr-26-a8	3	1	3	18	0	0	9	19	10	21	160	4
sr-26-a9	1	1	0	27	0	1	16	27	7	22	140	7
sr-26-a10	1	4	1	17	0	1	9	22	4	15	196	7
sr-26-a11	5	1	1	19	0	2	7	12	4	15	157	7
sr-26-c2	2	0	0	20	0	0	12	28	8	16	180	6
sr-26-c3	0	1	1	26	0	1	17	21	7	16	155	6
sr-26-c4	0	1	0	17	0	0	11	19	6	13	175	9
sr-26-c5	0	2	0	27	0	0	9	25	3	13	155	10
sr-26-c6	1	1	2	21	0	0	12	27	7	18	193	5
sr-26-c7	4	1	0	18	0	1	6	22	7	20	148	2
sr-26-c8	0	3	3	20	0	0	8	30	4	19	159	6
sr-26-c9	1	1	1	17	0	0	13	23	3	13	174	4
sr-26-c10	0	1	1	15	0	1	14	24	6	17	165	5
sr-26-c11	0	0	0	26	0	1	16	27	4	12	155	4
sr-26-c12	0	2	2	31	0	3	14	18	6	12	162	5
sr-26-c13	2	1	0	26	1	2	12	18	5	15	140	9

Table B.7. Raw data for phytolith family/subfamily representation for SR-26 data.

	Cyper	Agava	Ag/Alli	Polyp	Ulma	Dicot	Chlori	Panic	Pooid	Poac	Ppon	P/Pmon	P/Ppon
sr26a1	0.40%	1.12%	0.81%	0.00%	0.00%	5.26%	3.24%	7.69%	63.16%	1.62%	0.81%	1.21%	3.64%
sr26a2	0.00%	0.00%	0.42%	0.00%	0.00%	5.83%	3.33%	7.50%	63.75%	1.67%	0.00%	1.67%	4.58%
sr26a3	0.00%	0.40%	0.79%	0.00%	0.00%	5.93%	5.14%	8.30%	55.73%	3.95%	0.00%	2.77%	4.35%
sr26a4	0.77%	0.38%	0.00%	0.00%	0.00%	4.23%	1.92%	6.92%	66.92%	1.15%	1.15%	1.15%	5.38%
sr26a5	0.42%	0.42%	0.00%	0.00%	0.00%	4.58%	2.08%	5.83%	71.67%	0.83%	0.00%	0.42%	5.00%
sr26a6	0.37%	0.00%	0.37%	0.00%	0.00%	5.20%	2.60%	6.69%	66.54%	2.60%	0.37%	1.49%	5.20%
sr26a7	0.38%	1.51%	0.75%	0.00%	0.00%	4.91%	3.77%	8.68%	64.15%	1.89%	0.38%	0.38%	3.02%
sr26a8	1.21%	0.40%	1.21%	0.00%	0.00%	3.63%	4.03%	8.47%	64.52%	1.61%	1.21%	1.61%	4.44%
sr26a9	0.40%	0.40%	0.00%	0.00%	0.40%	6.43%	2.81%	8.84%	56.22%	2.81%	0.80%	2.01%	8.03%
sr26a10	0.36%	1.44%	0.36%	0.00%	0.36%	3.25%	1.44%	5.42%	70.76%	2.53%	0.00%	0.72%	5.42%
sr26a11	2.17%	0.43%	0.43%	0.00%	0.87%	3.04%	1.74%	6.52%	68.26%	3.04%	0.00%	0.87%	7.39%
sr26c2	0.74%	0.00%	0.00%	0.00%	0.00%	4.41%	2.94%	5.88%	66.18%	2.21%	0.00%	1.47%	5.88%
sr26c3	0.00%	0.40%	0.40%	0.00%	0.40%	6.77%	2.79%	6.37%	61.75%	2.39%	0.40%	3.19%	6.77%
sr26c4	0.00%	0.40%	0.00%	0.00%	0.00%	4.38%	2.39%	5.18%	69.72%	3.59%	0.40%	0.80%	5.58%
sr26c5	0.00%	0.82%	0.00%	0.00%	0.00%	3.69%	1.23%	5.33%	63.52%	4.10%	0.82%	2.87%	7.38%
sr26c6	0.35%	0.35%	0.70%	0.00%	0.00%	4.18%	2.44%	6.27%	67.25%	1.74%	0.00%	1.74%	5.57%
sr26c7	1.75%	0.44%	0.00%	0.00%	0.44%	2.62%	3.06%	8.73%	64.63%	0.87%	0.00%	0.87%	6.99%
sr26c8	0.00%	1.19%	1.19%	0.00%	0.00%	3.17%	1.59%	7.54%	63.10%	2.38%	0.00%	1.59%	6.35%
sr26c9	0.40%	0.40%	0.40%	0.00%	0.00%	5.20%	1.20%	5.20%	69.60%	1.60%	0.00%	1.20%	5.60%
sr26c10	0.40%	0.40%	6.02%	0.00%	0.40%	5.62%	2.41%	6.83%	66.27%	2.01%	0.00%	1.61%	4.42%
sr26c11	0.00%	0.00%	0.00%	0.00%	0.41%	6.53%	1.63%	4.90%	63.27%	1.63%	0.00%	3.67%	6.94%
sr26c12	0.00%	0.08%	0.78%	0.00%	1.18%	5.49%	2.35%	4.71%	63.53%	1.96%	0.00%	3.53%	8.63%
sr26c13	0.87%	0.43%	0.00%	0.43%	0.87%	5.19%	2.16%	6.49%	60.61%	3.90%	0.00%	3.03%	8.23%

Table B.8. Percentages of phytolith family/subfamily representation.

Sam#	sr26a1	sr26a2	sr26a3	sr26a4	sr26a5	sr26a6	sr26a7	sr26a8	sr26a9	sr26a10	sr26a11	sr26c2	sr26c3	sr26c4	sr26c5	sr26c6	sr26c7	sr26c8	sr26c9	sr26c10	sr26c11	sr26c12	sr26c13
sr26a1	na																						
sr26a2	8.75%	na																					
sr26a3	17.24%	22.29%	na																				
sr26a4	12.22%	16.95%	25.10%	na																			
sr26a5	16.96%	21.27%	32.76%	10.58%	na																		
sr26a6	11.42%	15.23%	22.38%	6.94%	11.58%	na																	
sr26a7	6.24%	9.37%	20.58%	14.18%	18.42%	13.38%	na																
sr26a8	11.36%	17.11%	21.48%	11.56%	18.42%	10.96%	10.82%	na															
sr26a9	18.07%	23.18%	12.13%	22.15%	30.97%	21.39%	21.49%	23.07%	na														
sr26a10	19.22%	25.25%	33.58%	13.98%	8.32%	12.02%	19.96%	17.68%	31.87%	na													
sr26a11	23.42%	28.17%	33.52%	13.10%	17.62%	13.04%	24.84%	16.08%	29.95%	12.86%	na												
sr26c2	11.16%	15.03%	22.86%	5.08%	12.16%	5.46%	12.78%	11.52%	20.85%	14.12%	15.26%	na											
sr26c3	14.64%	18.55%	21.02%	16.26%	21.48%	11.76%	18.70%	16.26%	12.53%	21.10%	20.04%	14.48%	na										
sr26c4	19.16%	23.03%	27.98%	11.74%	8.84%	9.12%	20.54%	15.86%	28.55%	7.54%	12.68%	10.64%	18.34%	na									
sr26c5	16.37%	21.54%	24.63%	14.01%	21.63%	16.03%	19.13%	18.73%	18.46%	18.49%	19.85%	12.85%	12.97%	16.11%	na								
sr26c6	11.61%	16.64%	24.15%	4.25%	9.93%	4.99%	13.29%	10.43%	23.44%	11.53%	12.57%	5.01%	14.37%	9.15%	14.84%	na							
sr26c7	12.87%	18.10%	24.61%	9.17%	18.01%	13.21%	12.85%	7.87%	20.16%	19.57%	15.83%	10.73%	17.15%	19.15%	17.06%	11.50%	na						
sr26c8	8.80%	16.35%	18.78%	11.98%	21.78%	14.16%	13.62%	12.96%	19.83%	17.72%	18.68%	12.82%	15.26%	19.68%	11.57%	12.71%	12.75%	na					
sr26c9	15.04%	19.81%	28.54%	9.02%	7.24%	8.32%	17.56%	16.38%	27.55%	7.90%	14.94%	10.02%	18.16%	6.60%	16.79%	6.95%	17.37%	17.86%	na				
sr26c10	18.84%	13.07%	33.14%	18.34%	21.72%	16.24%	17.28%	22.66%	32.13%	24.38%	27.12%	18.14%	24.54%	23.60%	28.37%	16.65%	23.67%	24.14%	20.26%	na			
sr26c11	13.56%	16.73%	24.10%	14.24%	21.24%	15.50%	19.40%	20.08%	14.67%	22.14%	23.26%	13.04%	8.86%	19.70%	8.65%	15.33%	17.67%	13.30%	15.66%	25.82%	na		
sr26c12	17.82%	21.75%	28.76%	18.54%	22.72%	14.80%	21.20%	17.28%	21.07%	21.52%	19.60%	16.56%	10.18%	17.62%	12.67%	15.97%	20.27%	18.52%	18.14%	26.58%	9.68%	na	
sr26c13	19.18%	25.09%	22.46%	17.92%	24.04%	15.44%	23.14%	18.62%	14.59%	23.34%	18.84%	17.70%	8.66%	18.68%	11.91%	18.47%	19.73%	19.20%	21.62%	29.10%	14.46%	11.50%	na

Table B.9. SR-26 dissimilarity matrix.

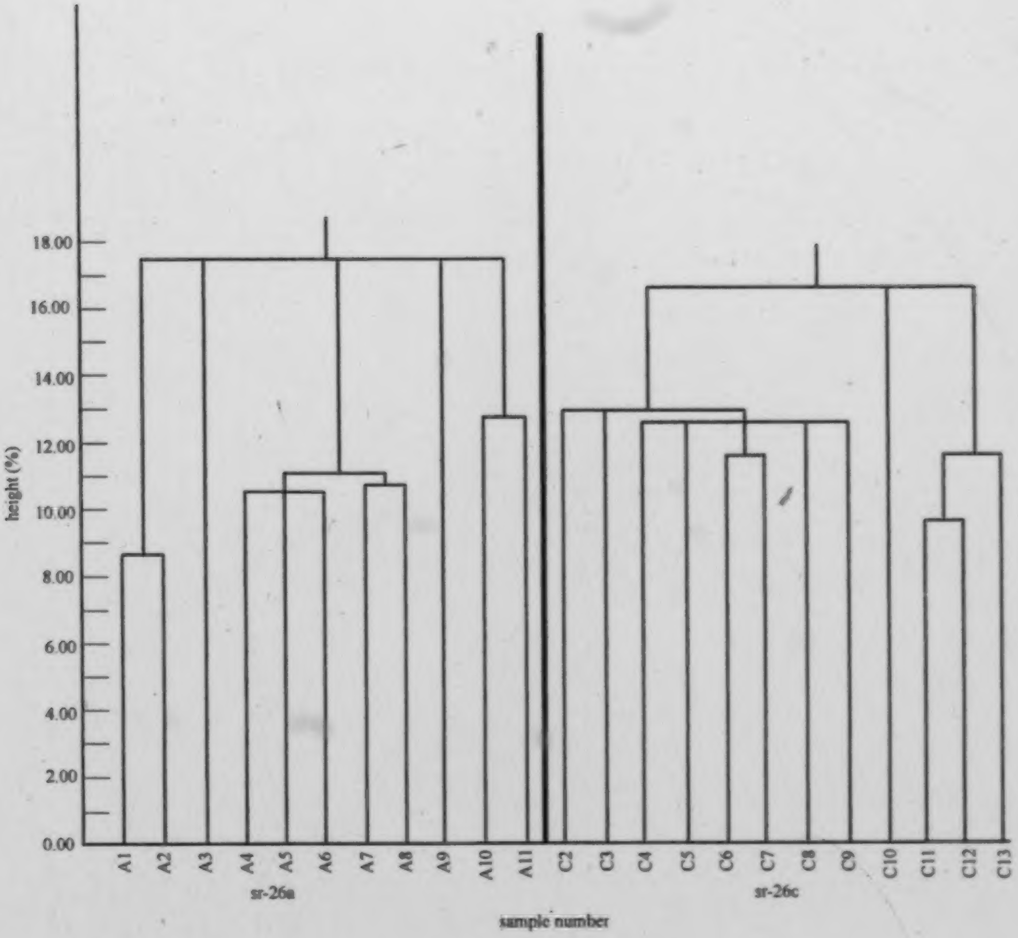

Figure B.3. Constrained Single Link Method dendrogram.

morphotype frequency throughout the profile (Figure B.4). No zones could be delineated in the SR-26 data due to the similarity of the sample phytolith spectra.

Table B.10. Summary of agglomeration heights using the CSLM of phytolith zonation for SR-26A.

Agglomeration Stage	Grouping	Height
1	A1, A2	8.75
2	A4, A5	10.58
3	(A4,A5), A6	10.58
4	A7, A8	10.82
5	(A4-A6), (A7,A8)	10.96
6	A10, A11	12.86
7	(A1,A2), A3)	17.24
8	(A1-A3), (A4-A8)	17.24
9	(A1-A8), A9	17.24

Table B.11. Summary of agglomeration heights using the CSLM of phytolith zonation for SR-26C.

Agglomeration Stage	Grouping	Height
1	C11, C12	9.68
2	C6, C7	11.50
3	(C11, C12), C13	11.50
4	(C6, C7), C8	12.71
5	(C6-C8), C9	12.71
6	C5, (C6-C9)	12.71
7	C4, (C5-C9)	12.71
8	C3, (C4-C9)	12.97
9	C2, (C3-C9)	12.97
10	(C2-C9), C10	16.65

B.1.8. Summary of CSLM

The advantages of a numerical approach to phytolith zonation may be summarized in four points (Birks and Gordon 1985):

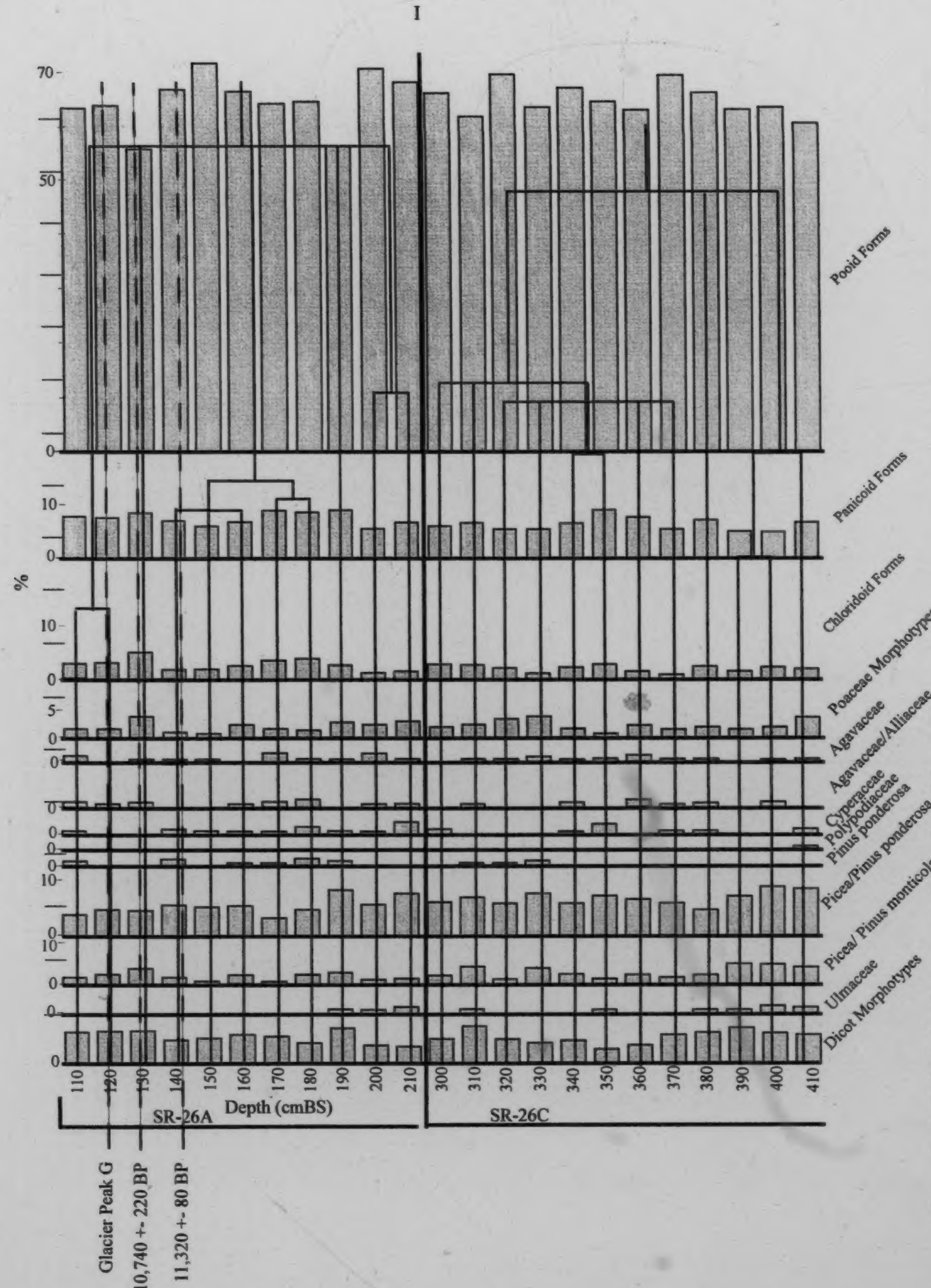

Figure B.4. CSLM dendrogram and the phytolith profile.

Power

The complexity of the data set does not allow for a simple scan and delimitation of zones. The number of variables over a series of strata make a simple “scan and understand” method rather difficult.

Consistency

The application of quantitative methods has the advantage that the same criteria can be applied to any number of data sets. This eliminates the possibility of investigators’ bias (e.g., an unconscious bias from results of a previous or completely different study and having these influence the interpretation of another data set). It also avoids forcing phytolith zones to coincide with pollen, stratigraphic, chronometric, or other zonations. Indeed, phytolith zones should be based solely on in phytolith morphotype frequencies without consideration of other stratigraphic delimiters.

Formulation of Criteria

Quantitative analysis methods such as applied here require the investigator to define criteria for analysing data and the goals and assumptions of the study. Also, quantitative analysis allows other researchers to understand and evaluate the primary data and the criteria for zonation. Thus, other researchers are able to repeat the steps and arrive at similar zone placements.

Rapidity of Implementation

While getting to the point of being able to apply these numerical methods is extremely intensive (recovering samples from the field, transporting and processing samples to get them to a viewable form, and the actual analysis of the samples themselves), the amount of time required to calculate the CSLM is minimal and much faster than the time required for and the uncertainties inherent in ‘eyeballing’ the data.

There are some problems with numerical methods. One of these is that it is difficult to quantify oftentimes legitimate intuitive 'hunches' a researcher may have towards a body of data (Birks and Gordon 1985). Numbers may sometimes be blind to what is obvious to the researcher. For this reason, numerical zonation methods such as CSLM should not be considered definitive or completely 'objective'. It is an excellent starting point but should not overrule the researcher's judgement. For example numerical methods may distinguish phytolith zones which actually are of little importance in defining zones from a data set (Birks and Gordon 1985). In other words, by the very nature of the test, zones will be established even if they are of little importance. In other instances, numerical zonation may overlook the importance of non-prominent indicator species.

B.2. Principal Components Analysis

Principal Components Analysis (PCA) is useful for reducing multidimensional data into a readily comprehensible format. It is a multidimensional scaling method (MDS) capable of representing populations (e.g., phytolith spectra) as points in a co-ordinate system in such a way that the distance between points conveys information about any similarities between them (Prentice 1980). The technique identifies axes (called components) in order of decreasing importance based on the variance of data. This type of ordination can convey relationships between phytolith spectra in a few dimensions (Grimm 1988; Birks *et al*. 1975). Components thus identified can be used to construct a number of two or three-dimensional plots in which the multidimensional variation in the original data can be depicted.

Ordinary PCA based on a correlation matrix was run using SPSS ver.10 (SSPS Inc., Illinois). A dissimilarity matrix, which is a measure of the degree of resemblance between every pair of phytolith spectra, was constructed. The second step was the conversion of this matrix into a configuration of points in *k*-dimensional space, where *k* is the number of populations minus one. Data were centered and the resulting dissimilarity coefficient is called the Euclidean distance. A scaling process converts the multidimensional dissimilarity matrix into a manageable, low-dimensional configuration making data diversity easier to portray and understand. For clarity, only two dimensions were used.

The first calculated principal component is the linear combination which accounts for the maximum possible proportion of variance of a set of variables (Prentice 1980). The second principal component is the maximum proportion of the remaining variance (being uncorrelated with the first), and so on (Prentice 1980). Each component, the Eigenvector, is associated with an Eigenvalue, being the amount of variance of that component. As the first sets of components (i.e. 1,2,3…) contain most of the variation between assemblages, they describe the data most succinctly. As the remainder typically account for only a small amount of variance they may be disregarded with little loss of information (Birks *et al.* 1975).

B.2.1. PCA Results for Hammer Creek

PCA values derived from both percentages and raw data scores produced similar values (Ritchie and Yarranton 1978). For this study, percentage data were used. As pooid forms are the majority of morphotypes, they mask variation in other assemblage components (Table B.12). Therefore, they were excluded recognizing that any detected variation is representative of changes occurring in a predominantly C_3 grassland environment. Non-grass species are known to be underproducers and therefore, even slight changes in their representation may be important.

Principal component ordinates may be viewed as approximations of the rate and direction of vegetation change, a reflection of vegetation stability or instability, as well as a measure of assemblage homo- or heterogeneity (Ritchie 1977; MacDonald and Ritchie 1986). When applied to phytolith records, the concept of stability describes a state of dynamic equilibrium where vegetation composition and structure is relatively constant over periods ranging from centuries to millennia. The results of this calculation are shown in Table B.13., a table of loadings of phytolith components, and Table B.14., a table of loadings for phytolith spectra for SR-23. Figure 5.7 – is a

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	34.809	99.453	99.453	34.809	99.453	99.453
2	9.061E-02	.259	99.712			
3	3.605E-02	.103	99.815			
4	2.233E-02	6.380E-02	99.879			
5	1.366E-02	3.904E-02	99.918			
6	1.214E-02	3.468E-02	99.953			
7	5.859E-03	1.674E-02	99.969			
8	4.390E-03	1.254E-02	99.982			
9	3.093E-03	8.837E-03	99.991			
10	1.902E-03	5.435E-03	99.996			
11	7.751E-04	2.214E-03	99.999			
12	4.953E-04	1.415E-03	100.000			
13	2.633E-05	7.523E-05	100.000			
14	2.146E-15	6.132E-15	100.000			
15	1.167E-15	3.335E-15	100.000			
16	1.031E-15	2.945E-15	100.000			
17	8.480E-16	2.423E-15	100.000			
18	7.700E-16	2.200E-15	100.000			
19	5.764E-16	1.647E-15	100.000			
20	4.128E-16	1.179E-15	100.000			
21	3.319E-16	9.484E-16	100.000			
22	3.182E-16	9.091E-16	100.000			
23	2.799E-16	7.998E-16	100.000			
24	1.021E-16	2.916E-16	100.000			
25	2.147E-17	6.133E-17	100.000			
26	-3.384E-17	-9.669E-17	100.000			
27	-1.734E-16	-4.954E-16	100.000			
28	-2.857E-16	-8.163E-16	100.000			
29	-3.129E-16	-8.941E-16	100.000			
30	-3.970E-16	-1.134E-15	100.000			
31	-4.787E-16	-1.368E-15	100.000			
32	-7.446E-16	-2.127E-15	100.000			
33	-8.408E-16	-2.402E-15	100.000			
34	-1.104E-15	-3.155E-15	100.000			
35	-7.621E-15	-2.177E-14	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component
	1
SR2300	.998
SR2301	.998
SR2302	.996
SR2303	.999
SR2304	.997
SR2305	.998
SR2306	.998
SR2307	.998
SR2308	.998
SR2309	.998
SR2310	.996
SR2311	.995
SR2313	.998
SR2319	.998
SR2320	.998
SR2321	.999
SR2322	.998
SR2323	.998
SR2324	.999
SR2325	.995
SR2326	.990
SR2327	.995
SR2328	.991
SR2329	.997
SR2330	.998
SR2331	.999
SR2332	.998
SR2333	.995
SR2334	.998
SR2335	.998
SR2336	.998
SR2337	.999
SR2338	.999
SR2339	.998
SR2340	.999

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

Communalities

	Initial	Extraction
SR2300	1.000	.996
SR2301	1.000	.997
SR2302	1.000	.992
SR2303	1.000	.998
SR2304	1.000	.994
SR2305	1.000	.996
SR2306	1.000	.996
SR2307	1.000	.996
SR2308	1.000	.996
SR2309	1.000	.995
SR2310	1.000	.993
SR2311	1.000	.991
SR2313	1.000	.995
SR2319	1.000	.996
SR2320	1.000	.996
SR2321	1.000	.998
SR2322	1.000	.996
SR2323	1.000	.996
SR2324	1.000	.998
SR2325	1.000	.990
SR2326	1.000	.981
SR2327	1.000	.990
SR2328	1.000	.983
SR2329	1.000	.994
SR2330	1.000	.997
SR2331	1.000	.998
SR2332	1.000	.997
SR2333	1.000	.990
SR2334	1.000	.996
SR2335	1.000	.996
SR2336	1.000	.996
SR2337	1.000	.998
SR2338	1.000	.997
SR2339	1.000	.997
SR2340	1.000	.998

Extraction Method: Principal Component Analysis.

Tables B.12. PCA loadings of sample variance of all variables.

Communalities

	Initial	Extraction
CYPER	1.000	.683
AGAV	1.000	.710
AGAV/ALLI	1.000	.585
POLYP	1.000	.488
C.RETIC	1.000	.826
DICOT	1.000	.705
CHLORID	1.000	.764
PANIC	1.000	.773
POAC	1.000	.551
PSEUDOT	1.000	.785
P.POND	1.000	.841
PICPMNT	1.000	.847
PICPPON	1.000	.867

Extraction Method: Principal Component Analysis.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.516	19.352	19.352	2.516	19.352	19.352
2	2.302	17.710	37.062	2.302	17.710	37.062
3	1.848	14.217	51.279	1.848	14.217	51.279
4	1.422	10.939	62.218	1.422	10.939	62.218
5	1.337	10.284	72.503	1.337	10.284	72.503
6	.892	6.862	79.364			
7	.846	6.510	85.875			
8	.568	4.370	90.245			
9	.462	3.552	93.797			
10	.332	2.558	96.354			
11	.188	1.447	97.801			
12	.166	1.279	99.080			
13	.120	.920	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component				
	1	2	3	4	5
CYPER	-.468	.417	.526	-5.561E-02	-.107
AGAV	.201	.657	-.158	-.455	-7.250E-02
AGAV/ALLI	.406	.437	-.241	7.490E-02	-.407
POLYP	-3.502E-02	-.498	-4.452E-02	-.482	-7.123E-02
C.RETIC	.492	-.286	.650	.193	-.208
DICOT	.245	-.388	1.033E-02	.543	-.446
CHLORID	-.168	.583	.625	-1.799E-02	-7.300E-02
PANIC	.477	.379	-.389	.462	.191
POAC	-.144	.313	.497	.271	.335
PSEUDOT	.131	-.124	-3.387E-02	.145	.854
P.POND	.845	.270	.196	.102	6.568E-02
PICPMNT	.462	-.576	.483	-.241	.103
PICPPON	.753	.158	3.800E-02	-.515	9.072E-02

Extraction Method: Principal Component Analysis.

a. 5 components extracted.

Tables B.13. PCA loadings of components (phytolith morphotypes).

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	23.323	66.638	66.638	23.323	66.638	66.638
2	3.701	10.573	77.212	3.701	10.573	77.212
3	2.742	7.834	85.046	2.742	7.834	85.046
4	1.663	4.752	89.798	1.663	4.752	89.798
5	1.235	3.528	93.325	1.235	3.528	93.325
6	.850	2.427	95.753			
7	.636	1.815	97.568			
8	.494	1.411	98.979			
9	.197	.563	99.542			
10	9.657E-02	.276	99.818			
11	6.081E-02	.174	99.991			
12	3.028E-03	8.652E-03	100.000			
13	2.653E-15	7.579E-15	100.000			
14	1.025E-15	2.928E-15	100.000			
15	8.016E-16	2.290E-15	100.000			
16	6.720E-16	1.920E-15	100.000			
17	5.942E-16	1.698E-15	100.000			
18	4.695E-16	1.341E-15	100.000			
19	4.101E-16	1.172E-15	100.000			
20	3.220E-16	9.200E-16	100.000			
21	2.820E-16	8.057E-16	100.000			
22	2.069E-16	5.912E-16	100.000			
23	1.360E-16	3.886E-16	100.000			
24	9.346E-17	2.670E-16	100.000			
25	6.143E-17	1.755E-16	100.000			
26	-4.791E-19	-1.369E-18	100.000			
27	-5.497E-17	-1.571E-16	100.000			
28	-8.690E-17	-2.483E-16	100.000			
29	-1.223E-16	-3.495E-16	100.000			
30	-1.430E-16	-4.087E-16	100.000			
31	-2.925E-16	-8.356E-16	100.000			
32	-3.928E-16	-1.122E-15	100.000			
33	-4.415E-16	-1.261E-15	100.000			
34	-4.496E-16	-1.285E-15	100.000			
35	-3.832E-15	-1.095E-14	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component				
	1	2	3	4	5
SR2300	.671	.596	-.101	-.207	-6.605E-02
SR2301	.658	.639	-1.232E-02	-.288	.176
SR2302	.453	.831	.211	-.210	5.535E-02
SR2303	.766	.419	5.610E-02	-.284	-.289
SR2304	.850	.340	-.266	.138	-4.974E-02
SR2305	.806	.107	-.556	.111	.105
SR2306	.906	-.111	-.282	5.634E-02	-.111
SR2307	.857	-4.243E-02	-.137	-4.779E-02	-.461
SR2308	.919	.131	-.222	.102	.125
SR2309	.891	6.182E-02	.255	-5.061E-02	-.350
SR2310	.621	-7.717E-02	.624	.420	-4.178E-02
SR2311	.657	.220	.641	.272	4.382E-03
SR2313	.814	.331	.403	.160	-6.794E-03
SR2319	.956	-4.360E-02	-2.259E-02	-1.257E-03	.211
SR2320	.901	2.264E-02	-.318	-5.391E-03	2.715E-02
SR2321	.901	-.333	-8.469E-02	-9.239E-02	-9.620E-02
SR2322	.813	-.245	.446	-.220	-4.897E-02
SR2323	.894	-.361	7.142E-02	-.178	-.148
SR2324	.934	-6.845E-02	.125	-.176	.186
SR2325	.912	-.287	8.422E-02	-.219	-6.162E-02
SR2326	.879	-.259	6.302E-02	-.350	.122
SR2327	.897	-6.030E-02	-.282	-.290	7.976E-02
SR2328	.661	-.381	.206	-.115	.574
SR2329	.856	-.143	.312	-.330	7.927E-03
SR2330	.750	.611	7.542E-02	9.114E-02	.106
SR2331	.831	-.500	.167	-6.109E-02	-2.528E-02
SR2332	.946	-.145	-.236	.108	.105
SR2333	.784	4.377E-02	-.586	.130	6.573E-02
SR2334	.763	-.375	7.292E-02	5.266E-02	.280
SR2335	.717	-.172	-.113	-6.972E-02	-.253
SR2336	.675	.287	.175	.371	.202
SR2337	.882	.248	-.182	.204	9.764E-02
SR2338	.826	-.266	-.213	.351	-9.081E-02
SR2339	.823	-.292	-3.159E-02	.375	-.107
SR2340	.850	4.276E-02	.144	.323	-.166

Extraction Method: Principal Component Analysis.

a. 5 components extracted.

Communalities

	Initial	Extraction
SR2300	1.000	.863
SR2301	1.000	.955
SR2302	1.000	.988
SR2303	1.000	.929
SR2304	1.000	.930
SR2305	1.000	.993
SR2306	1.000	.927
SR2307	1.000	.970
SR2308	1.000	.937
SR2309	1.000	.989
SR2310	1.000	.959
SR2311	1.000	.985
SR2313	1.000	.960
SR2319	1.000	.961
SR2320	1.000	.915
SR2321	1.000	.949
SR2322	1.000	.971
SR2323	1.000	.989
SR2324	1.000	.958
SR2325	1.000	.975
SR2326	1.000	.980
SR2327	1.000	.980
SR2328	1.000	.968
SR2329	1.000	.960
SR2330	1.000	.980
SR2331	1.000	.973
SR2332	1.000	.984
SR2333	1.000	.980
SR2334	1.000	.809
SR2335	1.000	.625
SR2336	1.000	.747
SR2337	1.000	.924
SR2338	1.000	.929
SR2339	1.000	.915
SR2340	1.000	.873

Extraction Method: Principal Component Analysis.

Tables B.14. PCA loadings of sample variance (phytolith spectra).

map of the component scores and Figure 5.8 - a plot of the component scores of phytolith spectra. PCA time trend diagrams (Figure 5.9) provide a means of examining the rate of vegetation change evident from the phytolith record.

The time trend was constructed by calculating the means of the weightings of each phytolith zone with crossbars representing standard deviations. These points were connected to show the temporal trend and a series of extrapolated radiocarbon ages were shown beside appropriate points along this time line.

B.2.2. PCA Results for Lyons Bar

The results of SSPS calculations are shown in Table B.15. – the results of PCA loadings for all phytolith spectra, Table B.16. – a table of loadings of phytoliths components and Table B.17. – a table of loadings for phytolith spectra without pooid forms. Figure 5.4 – is a map of the component scores and Figure 5.5 - a plot of the component scores on principal components. PCA time trend diagrams (Figure 5.6) provide a means of examining the rate of vegetation change evident from the phytolith record.

The time trend was constructed by calculating the means of the weightings of each phytolith zone with crossbars representing standard deviations. These points were joined in order to show the temporal trend and a series of ^{14}C ages were extrapolated and applied to the trend line in order to set these changes in a temporal framework.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	22.935	99.716	99.716	22.935	99.716	99.716
2	2.368E-02	.103	99.819			
3	1.514E-02	6.585E-02	99.885			
4	1.114E-02	4.843E-02	99.934			
5	5.576E-03	2.424E-02	99.958			
6	4.507E-03	1.960E-02	99.977			
7	2.244E-03	9.757E-03	99.987			
8	1.459E-03	6.344E-03	99.994			
9	8.195E-04	3.563E-03	99.997			
10	4.777E-04	2.077E-03	99.999			
11	1.147E-04	4.989E-04	100.000			
12	6.326E-05	2.750E-04	100.000			
13	1.150E-15	4.999E-15	100.000			
14	5.234E-16	2.276E-15	100.000			
15	4.788E-16	2.082E-15	100.000			
16	2.826E-16	1.229E-15	100.000			
17	2.209E-16	9.605E-16	100.000			
18	2.277E-17	9.899E-17	100.000			
19	-4.499E-17	-1.956E-16	100.000			
20	-1.356E-16	-5.897E-16	100.000			
21	-2.938E-16	-1.277E-15	100.000			
22	-3.363E-16	-1.462E-15	100.000			
23	-5.963E-16	-2.593E-15	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component
	1
A1	.999
A2	.999
A3	.997
A4	1.000
A5	.999
A6	1.000
A7	.998
A8	.999
A9	.997
A10	.999
A11	.999
C2	1.000
C3	.999
C4	.999
C5	.998
C6	1.000
C7	.998
C8	.999
C9	.999
C10	.996
C11	.998
C12	.998
C13	.998

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

Communalities

	Initial	Extraction
A1	1.000	.998
A2	1.000	.999
A3	1.000	.993
A4	1.000	.999
A5	1.000	.999
A6	1.000	1.000
A7	1.000	.995
A8	1.000	.997
A9	1.000	.994
A10	1.000	.998
A11	1.000	.997
C2	1.000	1.000
C3	1.000	.998
C4	1.000	.998
C5	1.000	.996
C6	1.000	1.000
C7	1.000	.996
C8	1.000	.998
C9	1.000	.999
C10	1.000	.992
C11	1.000	.996
C12	1.000	.995
C13	1.000	.997

Extraction Method: Principal Component Analysis.

Tables B.15. PCA loadings of sample variance
of all variables.

Communalities

	Initial	Extraction
CYPER	1.000	.918
AGAV	1.000	.800
AGAV/ALLI	1.000	.742
POLYP	1.000	.618
ULMA	1.000	.815
DICOT	1.000	.797
CHLORI	1.000	.838
PANIC	1.000	.846
POAC	1.000	.728
PPON	1.000	.868
PPMON	1.000	.825
PPPON	1.000	.860

Extraction Method: Principal Component Analysis.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.165	26.377	26.377	3.165	26.377	26.377
2	2.099	17.495	43.872	2.099	17.495	43.872
3	1.606	13.381	57.253	1.606	13.381	57.253
4	1.320	11.003	68.256	1.320	11.003	68.256
5	1.183	9.859	78.115	1.183	9.859	78.115
6	.764	6.369	84.484			
7	.616	5.136	89.620			
8	.564	4.700	94.320			
9	.288	2.403	96.723			
10	.243	2.026	98.749			
11	.119	.989	99.738			
12	3.147E-02	.262	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component				
	1	2	3	4	5
CYPER	-.147	-.701	.562	-.269	-.134
AGAV	-.436	-.293	-.151	.492	.510
AGAV/ALLI	-.174	.222	-1.294E-02	-.458	.673
POLYP	.508	-.156	.421	.262	.300
ULMA	.722	-.292	.306	-.283	.186
DICOT	.325	.823	-2.739E-04	-.118	1.489E-03
CHLORI	-.343	.551	.636	-8.482E-02	-3.162E-02
PANIC	-.579	.128	.696	4.101E-02	8.800E-02
POAC	.425	.106	.185	.637	.306
PPON	-.363	.157	.207	.698	-.422
PPMON	.755	.484	.116	7.108E-02	-4.137E-02
PPPON	.838	-.309	.121	4.560E-02	-.214

Extraction Method: Principal Component Analysis.

a. 5 components extracted.

Tables B.16. Placement of components (phytolith morphotypes).

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	20.403	88.709	88.709	20.403	88.709	88.709
2	1.120	4.871	93.579	1.120	4.871	93.579
3	.558	2.425	96.004			
4	.364	1.582	97.586			
5	.236	1.025	98.611			
6	.139	.606	99.217			
7	9.106E-02	.396	99.613			
8	4.785E-02	.208	99.821			
9	2.718E-02	.118	99.940			
10	7.475E-03	3.250E-02	99.972			
11	6.437E-03	2.799E-02	100.000			
12	1.484E-15	6.452E-15	100.000			
13	1.196E-15	5.199E-15	100.000			
14	4.007E-16	1.742E-15	100.000			
15	2.941E-16	1.279E-15	100.000			
16	1.334E-16	5.802E-16	100.000			
17	7.940E-17	3.452E-16	100.000			
18	5.020E-17	2.183E-16	100.000			
19	-3.560E-17	-1.548E-16	100.000			
20	-2.635E-16	-1.146E-15	100.000			
21	-3.564E-16	-1.549E-15	100.000			
22	-4.396E-16	-1.911E-15	100.000			
23	-9.194E-16	-3.998E-15	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component	
	1	2
A1	.934	.331
A2	.969	.186
A3	.919	.229
A4	.975	6.496E-02
A5	.980	5.927E-02
A6	.991	5.051E-02
A7	.882	.446
A8	.917	.335
A9	.995	-4.281E-02
A10	.962	-9.447E-02
A11	.919	-.172
C2	.989	-5.048E-02
C3	.966	-.123
C4	.960	-.112
C5	.902	-.358
C6	.997	6.513E-03
C7	.919	8.645E-02
C8	.960	-2.715E-03
C9	.974	-.114
C10	.768	.279
C11	.910	-.284
C12	.895	-.376
C13	.951	-.289

Extraction Method: Principal Component Analysis.

a. 2 components extracted.

Communalities

	Initial	Extraction
A1	1.000	.982
A2	1.000	.973
A3	1.000	.897
A4	1.000	.955
A5	1.000	.964
A6	1.000	.985
A7	1.000	.978
A8	1.000	.952
A9	1.000	.992
A10	1.000	.935
A11	1.000	.874
C2	1.000	.980
C3	1.000	.948
C4	1.000	.933
C5	1.000	.942
C6	1.000	.994
C7	1.000	.853
C8	1.000	.921
C9	1.000	.961
C10	1.000	.668
C11	1.000	.908
C12	1.000	.941
C13	1.000	.989

Extraction Method: Principal Component Analysis.

Tables B.17. PCA loadings of sample variance (phytolith spectra).